

**AERONAUTICS**

---

**SIXTEENTH ANNUAL REPORT**

**OF THE**

**NATIONAL ADVISORY COMMITTEE**

**FOR AERONAUTICS**

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**1930**

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**INCLUDING TECHNICAL  
REPORTS Nos. 337 to 364**



**UNITED STATES  
GOVERNMENT PRINTING OFFICE  
WASHINGTON : 1931**

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## LETTER OF SUBMITTAL

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*To the Congress of the United States:*

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I submit herewith the sixteenth annual report of the committee for the fiscal year ended June 30, 1930.

Attention is invited to the opening portion of the committee's report dealing with the aeronautical situation generally, and also to Part V of the report presenting a summary of progress in the technical development of aircraft. It is gratifying to note therein, and in Chairman Ames's letter of transmittal, the committee's views as to the factors that have contributed to and assure the further progress of aeronautics.

I concur with the committee's recommendations at the end of the report regarding the further development of aircraft and the need for continued prosecution of scientific research in aeronautics.

HERBERT HOOVER.

THE WHITE HOUSE,  
December 4, 1930.





## LETTER OF TRANSMITTAL

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,  
*Washington, D. C., November 18, 1930.*

MR. PRESIDENT: In compliance with the provisions of the act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 153), I have the honor to transmit herewith the Sixteenth Annual Report of the National Advisory Committee for Aeronautics for the fiscal year ended June 30, 1930.

The year 1930 has been one of gratifying progress in scientific knowledge referring to aviation, in the technical development of aircraft, and in the extension of the use of aircraft in the United States. The policies of the Federal Government in supporting the study of the fundamental problems relating to the technical development of aircraft, and in providing airways and air navigation facilities, have been most important factors in the year's progress.

The encouragement provided by the Watres Act for the carrying of air mail and the transportation of passengers will enable air transportation companies to gain experience with the factors which will ultimately place air transportation on a sound economic basis. The important problems requiring solution are the improvement of aircraft and aircraft-engine design, resulting in more economical operation, and the development of improved facilities which will aid in the safety and reliability of aircraft operation. The committee believes that, with the completion of the full-scale wind tunnel and the seaplane towing channel at its laboratories at Langley Field, Va., it will be in a position to undertake more effectively the solution of those scientific problems which affect the safety and economy of aircraft.

The committee believes that the present policies of the Federal Government relating to the development of aeronautics in all its branches are sound and constructive, and that in the firm support of these policies lies the best assurance of the continued advancement and leadership of American aeronautics.

Respectfully submitted.

JOSEPH S. AMES,  
*Chairman.*

THE PRESIDENT,  
*The White House, Washington, D. C.*

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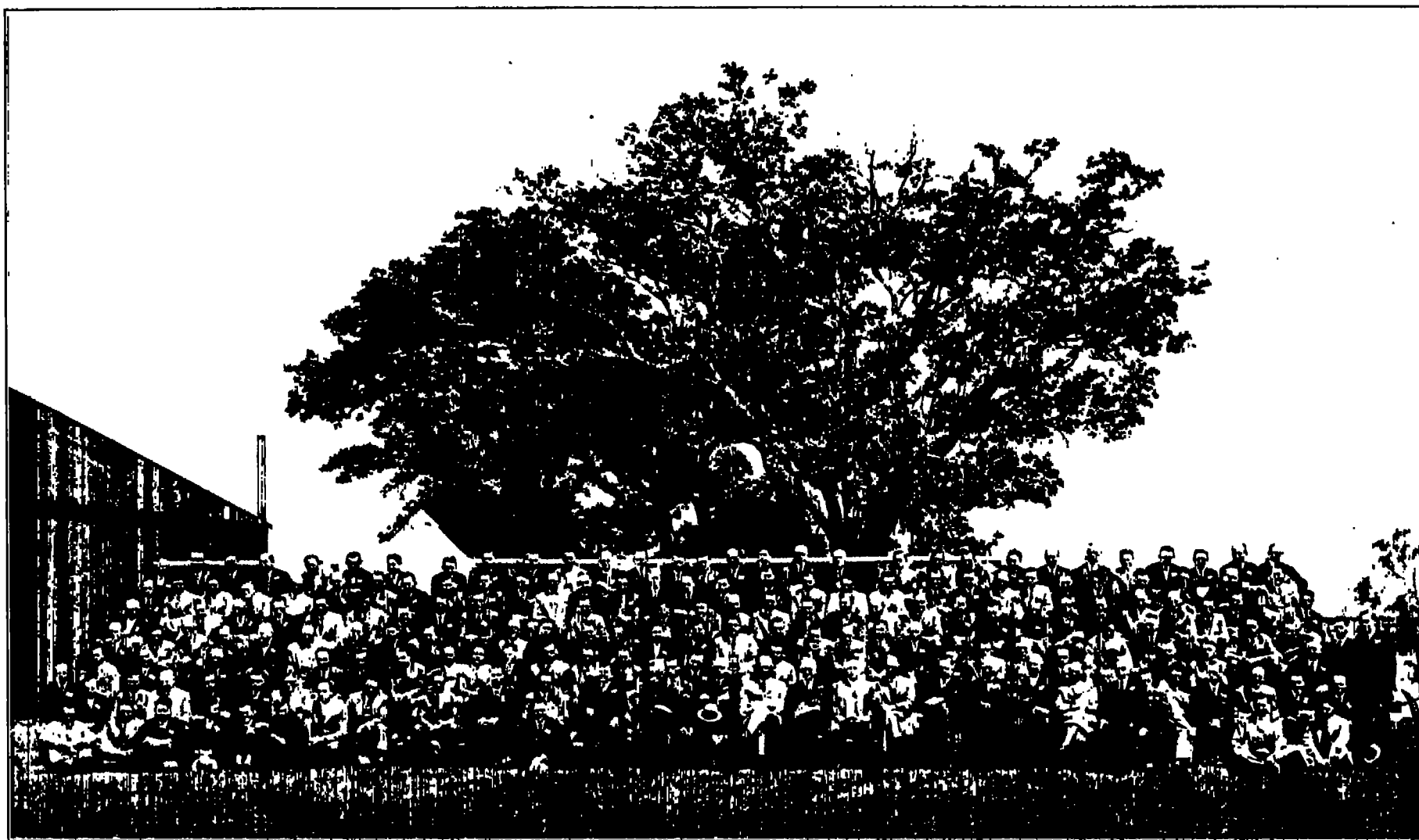
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FIFTH ANNUAL AIRCRAFT ENGINEERING RESEARCH CONFERENCE  
UNDER THE AUSPICES OF  
THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS  
LANGLEY FIELD, VA., MAY 13, 1930



# SIXTEENTH ANNUAL REPORT

of the

## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 11, 1930.*

*To the Congress of the United States:*

In accordance with the act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, the committee submits herewith its sixteenth annual report for the fiscal year 1930.

The outstanding evidence of progress during the past year has been the material increase in the operation of commercial aircraft and in the number of types of commercial aircraft developed. Commercial aviation is passing through its third fundamental stage of development and is about to enter upon the fourth stage. The first stage in the development of air transport in this country was the direct operation of the air mail service by the Post Office Department. The second stage was the operation of air-mail lines by contracts between the Post Office Department and air transport companies, and Federal regulation and assistance under the air commerce act. The third or present stage is the direct encouragement given air mail contractors to develop and use aircraft suitable for the carrying of passengers as well as mail. This encouragement results from the enactment of the Watres bill during the last session of the Congress. As the fourth stage we may expect to see the carrying of passengers and express become the major portion of the business of the operating air lines and the carrying of air mail become subordinate.

A striking demonstration of the practical utility of the airplane for the transportation of passengers in competition with excellent railroad service over a comparatively short distance is furnished by the New York to Washington air line. On this line airplanes leave every hour on the hour during the business day and frequently run double or triple sections. On a number of air lines the passenger rates are approximately equal to the cost of railroad fare plus the Pullman charge. With increased public confidence and support it may be possible in some cases to operate air passenger lines successfully at rates less than the cost of railroad travel plus the Pullman charge. Thus will commer-

cial aviation come to serve in increasing measure the demands of the people for rapid transportation and to find its true place in meeting the transportation needs of the country.

During the past year improvement in the design and performance of aircraft has been greater than was anticipated. This has no doubt been largely due to the general business depression, which induced a keener competition among designers and manufacturers to improve their product. Farsighted aircraft and engine manufacturers, while suffering from curtailment of production, have concentrated upon the essential needs of aircraft and accomplished substantial progress by the more active and thorough engineering application of scientific data produced by aeronautical research laboratories.

The aircraft industry is passing through a severe period of transition, which is witnessing the elimination of many of the weaker companies and the consolidation of others. This was inevitable, even without the spur of a general depression. With mushroom growth halted, there is promise that the overdeveloped industry will emerge from its present condition fortified by a sounder business and economic structure, with a more accurate appreciation of the true field of the airplane, and of its possibilities and limitations.

The airplane has been improved during the past year in speed, safety, comfort, reliability, cruising radius, and economy of maintenance and of operation. This progress has been concurrent with growth in other respects, evidenced by the following comparison of figures obtained from the Department of Commerce as of October 15, 1930, with those obtained as of November 1, 1929:

	1929	1930	Per cent increase
Miles of airways.....	35,000	47,000	34
Miles of airways lighted.....	12,500	14,000	12
Airports and landing fields.....	1,530	1,792	18
Scheduled transport service, miles daily.....	52,000	123,000	50
Civilian pilots licensed.....	8,900	14,900	67
Different airplane designs approved.....	170	379	123
Different airplane designs approved, having two or more engines.....	13	30	150
Different aircraft engine designs approved.....	32	64	100
Paid passengers, scheduled air transport—first six months of 1929 and of 1930.....	52,473	203,375	300

The foregoing figures indicate that the groundwork for the development of commercial aviation has been well laid. There has, however, been serious retrenchment and curtailed production in the aircraft industry, due to the general business depression and to the normal reaction following temporary overexpansion in certain phases of the industry.

The increase of 300 per cent in paid passengers is a most notable development for the year 1930, and gives assurance that the airplane is destined to become an important factor in transportation. The increase of 123 per cent in the number of different types of airplanes approved and of 150 per cent in the number of types having two or more engines indicates that aircraft designers are active, that competition is keen, and that the industry as a whole is trying to improve its product. This rapid increase in number of types may be considered a normal and healthy sign at this stage of the development of air transportation, and may be expected to continue until the industry enters the stage of standardization and mass production.

The continued expansion in aeronautical activities presents many problems. The necessity for the development of larger airplanes, and especially large flying boats, presents a variety of difficult problems, the solution of which can fortunately be undertaken promptly.

Progress has been made not only in increasing the size of airplanes but also in materially increasing speed. Increased speed of air transports presents further fundamental problems as to the structural strength of the aircraft when operating in disturbed air conditions. This series of problems is one of the most important demanding the immediate attention of the committee, and exact knowledge is being obtained by the use of special instruments designed by the committee and installed on air transports with the cooperation of the operating companies.

Accidents on scheduled air transport lines have been very few. This has been due not only to physical improvement of the airplane but largely to the extensive airways, navigation facilities, and weather-report service provided by the Federal Government. The air traveler along national airways is provided by the Government with intermediate landing fields, navigational lights, signals, and communication, including hourly weather reports. The modern airplane operated over an established airway by a competent pilot is a reasonably safe means of transportation.

The number of aircraft required to meet the demands of air transport lines and the military and naval needs would not maintain a large manufacturing industry, so that the industry will remain small unless or until the private use of aircraft is extensively developed. Improved operating technique, ground

facilities, and aids to air navigation will go far to promote safety on air transport lines, but will not be sufficient to make the airplane a popular vehicle for private use. To bring this about there must be material improvement in the safety of the private airplane and in its economy in first cost, maintenance, and operation.

The problems of the aircraft designer to-day are more difficult than ever. Formerly he had to meet primarily the demands of the military services for maximum performance and of the well-to-do private flyer, when the present paramount factors of aerodynamic safety, comfort, and economy were not so important, but to-day he is confronted with a variety of problems calling for greater safety, improved control at low speed incident to taking off and landing, higher speed in flight, increased comfort, less noise and vibration, and general reduction in cost without reduction in airworthiness requirements. At present there is no revolutionary principle nor startling invention in sight which will materially improve the airplane. In all probability development will be gradual and will be determined largely by the results of persistent and well-organized research. In the long run that country may be expected to lead in the development of the airplane that most effectively and persistently attacks the fundamental problems of flight. Because of the far-sightedness and liberal support of the President and of the Congress of the United States, equipment of great value for scientific research has been assembled by the committee at its laboratories at Langley Field, Va., including the full-scale wind tunnel, the variable-density wind tunnel, the propeller research tunnel, and the seaplane towing channel, which are unique and do not exist in operating form up to the present time in any other laboratory in the world. This equipment makes possible the thorough scientific investigation of the problems that mean most to the development of aircraft.

The first major investigation conducted in the propeller research tunnel led to the development of the "N. A. C. A. cowling," which, by decreasing the air resistance of air-cooled engines, has the effect either of materially increasing the speed of the airplane or of decreasing fuel consumption. In recognition of this contribution to progress, the Collier trophy was awarded to the committee by the National Aeronautic Association and was formally presented by President Hoover at a brief ceremony on the White House grounds on June 3, 1930, before a small but distinguished gathering of aeronautical authorities.

The Collier trophy is awarded annually by the National Aeronautic Association "for the greatest achievement in aviation in America, the value of which has been thoroughly demonstrated by actual use dur-



ing the preceding year." Senator Hiram Bingham, president of the National Aeronautic Association, opened the ceremony by explaining the history and status of the Collier trophy and read the citation of award. President Hoover, in presenting the trophy to Dr. Joseph S. Ames, chairman of the National Advisory Committee for Aeronautics, commended the committee on the scientific research which had developed the cowling. Doctor Ames, in accepting the trophy on behalf of the committee, said in part: "A scientist receives his reward from his own work in believing that he has added to human knowledge; but he is always gratified when his work is recognized as good by those competent to judge."

This annual report is submitted in five parts. Part I describes the organization of the committee, states its functions, outlines the facilities available under the committee's direction for the conduct of scientific research in aeronautics, explains the activities and growth of the Office of Aeronautical Intelligence in the collection, analysis, and dissemination of scientific and technical data, and presents a financial report of expenditures during the fiscal year ended June 30, 1930.

In Part II of this report the committee describes its miscellaneous activities, including the study of aircraft accidents, the consideration of aeronautical inventions and designs, its relations with the aircraft industry, and its cooperation with other governmental agencies.

In Part III the committee presents reports on the major results of its fundamental work in the form of reports of its standing technical subcommittees on aerodynamics, power plants for aircraft, materials for aircraft, and problems of air navigation, which include statements of the organization and the functions of each and of the progress of investigations conducted under their general cognizance in governmental and private laboratories.

In Part IV the committee presents summaries of the Technical Reports published during the past year, and enumerates by title the Technical Notes, Technical Memorandums, and Aircraft Circulars issued.

In Part V the committee presents a summary of progress in the technical development of aircraft. The report closes with a reference to the important factors that have contributed to the advancement of American aeronautics.

## PART I

### ORGANIZATION

#### FUNCTIONS OF THE COMMITTEE

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 151). The organic act charged the committee with the supervision and direction of the scientific study of the problems of flight with a view to their practical solution, the determination of problems which should be experimentally attacked, and their investigation and application to practical questions of aeronautics. The act also authorized the committee to direct and conduct research and experimentation in aeronautics in such laboratory or laboratories, in whole or in part, as may be placed under its direction.

Supplementing the prescribed duties of the committee under its organic act, its broad general functions may be stated as follows:

First. Under the law the committee holds itself at the service of any department or agency of the Government interested in aeronautics for the furnishing of information or assistance in regard to scientific or technical matters relating to aeronautics, and in particular for the investigation and study of fundamental problems submitted by the War and Navy Departments with a view to their practical solution.

Second. The committee may also exercise its functions for any individual, firm, association, or corporation within the United States, provided that such individual, firm, association, or corporation defray the actual cost involved.

Third. The committee institutes research, investigation, and study of problems which, in the judgment of its members or of the members of its various subcommittees, are needful and timely for the advance of the science and art of aeronautics in its various branches.

Fourth. The committee keeps itself advised of the progress made in research and experimental work in aeronautics in all parts of the world, particularly in England, France, Italy, Germany, and Canada.

Fifth. The information thus gathered is brought to the attention of the various subcommittees for consideration in connection with the preparation of programs for research and experimental work in this country. This information is also made available promptly to the military and naval air organizations and other branches of the Government and such as is not confidential is immediately released to university

laboratories and aircraft manufacturers interested in the study of specific problems, and also to the public.

Sixth. The committee holds itself at the service of the President, the Congress, and the executive departments of the Government for the consideration of special problems which may be referred to it.

By act of Congress approved July 2, 1926, and amended March 3, 1927 (U. S. C., Supp. I, title 10, sec. 310r), the committee was given an additional function. This legislation created and specified the functions of an Aeronautical Patents and Design Board, consisting of an Assistant Secretary of War, an Assistant Secretary of the Navy, and an Assistant Secretary of Commerce, and provided that upon favorable recommendation of the National Advisory Committee for Aeronautics the Patents and Design Board shall determine questions as to the use and value to the Government of aeronautical inventions submitted to any branch of the Government. The legislation provided that designs submitted to the board should be referred to the National Advisory Committee for Aeronautics for its recommendation and this has served to impose upon the committee the additional duty of considering on behalf of the Government all aeronautical inventions and designs submitted.

#### ORGANIZATION OF THE COMMITTEE

In accordance with the provisions of the act of Congress establishing the committee, as amended by act approved March 2, 1929 (U. S. C., Supp. III, title 50, sec. 151a), the National Advisory Committee for Aeronautics consists of 15 members appointed by the President, as follows: Two members from the War Department, from the office in charge of military aeronautics; 2 members from the Navy Department, from the office in charge of naval aeronautics; a representative each of the Smithsonian Institution, the United States Weather Bureau, and the United States Bureau of Standards; and not more than 8 additional persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences. The law further provides that all members as such shall serve without compensation.

On August 13, 1930, Brig. Gen. Benjamin D. Foulois, United States Army, submitted his resignation as a member of the committee on account of his relief

from duty as chief of the matériel division of the Air Corps, and under date of September 10, the President appointed Brig. Gen. Henry C. Pratt, General Foulois's successor as chief of the matériel division, to succeed him as a member of the committee. General Pratt executed the oath of office on September 20, 1930.

The entire committee meets twice a year, the annual meeting being held in October and the semiannual meeting in April. The present report includes the activities of the committee between the annual meeting held on October 24, 1929, and that held on October 23, 1930.

The organization of the committee at the close of the past year was as follows:

Joseph S. Ames, Ph. D., chairman, president of Johns Hopkins University, Baltimore, Md.  
 David W. Taylor, D. Eng., vice chairman, Washington, D. C.  
 Charles G. Abbot, Sc. D., secretary of the Smithsonian Institution.  
 George K. Burgess, Sc. D., Director of the Bureau of Standards.  
 William F. Durand, Ph. D., professor emeritus of mechanical engineering, Stanford University, California.  
 Maj. Gen. James E. Fechet, United States Army, Chief of the Air Corps.  
 Harry F. Guggenheim, M. A., American ambassador to Cuba.  
 William P. MacCracken, jr., Ph. B., Washington, D. C.  
 Charles F. Marvin, M. E., Chief of the Weather Bureau.  
 Rear Admiral William A. Moffett, United States Navy, Chief of the Bureau of Aeronautics, Navy Department.  
 Brig. Gen. Henry C. Pratt, United States Army, chief of the matériel division, Air Corps.  
 S. W. Stratton, Sc. D., Massachusetts Institute of Technology, Cambridge, Mass.  
 Capt. John H. Towers, United States Navy, Assistant Chief of the Bureau of Aeronautics, Navy Department.  
 Edward P. Warner, M. S., editor of "Aviation."  
 Orville Wright, Sc. D., Dayton, Ohio.

#### MEETINGS OF THE ENTIRE COMMITTEE

The semiannual meeting of the entire committee was held on April 24, 1930, at the committee's headquarters in Washington, and the annual meeting on October 23, 1930, also at the committee's headquarters. At these meetings the recent progress in aeronautical research was reviewed and some of the principal problems of aeronautics were discussed. Administrative

reports of the secretary, Mr. John F. Victory, and of the director of the office of aeronautical intelligence, Dr. Joseph S. Ames, were also submitted.

At both the annual and semiannual meetings detailed reports of the research work being conducted by the committee at the Langley Memorial Aeronautical Laboratory, Langley Field, Hampton, Va., were presented, and charts and photographs were exhibited showing the methods used and the results obtained in the more important investigations.

The election of officers was the concluding feature of the annual meeting. The officers of the committee were reelected for the ensuing year, as follows: Chairman, Dr. Joseph S. Ames; vice chairman, Dr. David W. Taylor; chairman executive committee, Dr. Joseph S. Ames; vice chairman executive committee, Dr. David W. Taylor.

#### THE EXECUTIVE COMMITTEE

For the purpose of carrying out the work of the Advisory Committee the regulations provide for the election annually of an executive committee, to consist of seven members and to include in addition any member of the Advisory Committee not otherwise a member of the executive committee but resident in or near Washington and giving his time wholly or chiefly to the special work of the committee. The present organization of the executive committee is as follows:

Joseph S. Ames, Ph. D., chairman.  
 David W. Taylor, D. Eng., vice chairman.  
 Charles G. Abbot, Sc. D.  
 George K. Burgess, Sc. D.  
 Maj. Gen. James E. Fechet, United States Army.  
 William P. MacCracken, jr.  
 Charles F. Marvin, M. E.  
 Rear Admiral William A. Moffett, United States Navy.  
 Brig. Gen. Henry C. Pratt, United States Army.  
 S. W. Stratton, Sc. D.  
 Capt. John H. Towers, United States Navy.  
 Edward P. Warner, M. S.  
 Orville Wright, Sc. D.

The executive committee, in accordance with general instructions of the Advisory Committee, performs the functions prescribed by law for the whole committee, administers the affairs of the committee, and exercises general supervision over all its activities.

The executive committee has organized the necessary clerical and technical staffs for handling the work of the committee proper. The total paid personnel of the committee numbered 254 employees on June 30, 1930, comprising 40 in Washington, 211 at the Langley Memorial Aeronautical Laboratory, Langley Field, Va., and 3 at the office of the technical assistant in Europe, Paris, France. General responsibility for the

execution of the policies and the direction of the activities approved by the executive committee is vested in the Director of Aeronautical Research, Mr. George W. Lewis. He has immediate charge of the scientific and technical work of the committee, being directly responsible to the chairman of the executive committee, Dr. Joseph S. Ames. The secretary, Mr. John F. Victory, is ex officio secretary of the executive committee, directs the administrative work of the organization, and exercises general supervision over the expenditures of funds and the employment of personnel.

#### SUBCOMMITTEES

In order to facilitate the conduct of its work the executive committee has organized the following standing committees with subcommittees as indicated:

##### Aerodynamics—

Subcommittee on airships.

Subcommittee on aeronautical research in universities.

Power plants for aircraft.

##### Materials for aircraft—

Subcommittee on metals.

Subcommittee on woods and glues.

Subcommittee on coverings, dopes, and protective coatings.

Subcommittee on aircraft structures.

##### Problems of air navigation—

Subcommittee on problems of communication.

Subcommittee on instruments.

Subcommittee on meteorological problems.

Aircraft accidents.

Aeronautical inventions and designs.

Publications and intelligence.

Personnel, buildings, and equipment.

Governmental relations.

The organization and work of the technical committees on aerodynamics, power plants for aircraft, materials for aircraft, and problems of air navigation are covered in the reports of those committees in Part III of this report, while the activities of the committee on aircraft accidents and the committee on aeronautical inventions and designs are included in Part II under the subjects of the study of aircraft accidents and the consideration of aeronautical inventions, respectively.

Statements of the organization and functions of the administrative committees on publications and intelligence; personnel, buildings, and equipment; and governmental relations follow:

#### COMMITTEE ON PUBLICATIONS AND INTELLIGENCE

##### FUNCTIONS

1. The collection, classification, and diffusion of technical knowledge on the subject of aeronautics, in-

cluding the results of research and experimental work done in all parts of the world.

2. The encouragement of the study of the subject of aeronautics in institutions of learning.

3. Supervision of the office of aeronautical intelligence.

4. Supervision of the committee's foreign office in Paris.

5. The collection and preparation for publication of the Technical Reports, Technical Notes, Technical Memorandums, and Aircraft Circulars of the committee.

##### ORGANIZATION

Dr. Joseph S. Ames, chairman.

Prof. Charles F. Marvin, vice chairman.

Miss M. M. Muller, secretary.

#### COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

##### FUNCTIONS

1. To handle all matters relating to personnel, including the employment, promotion, discharge, and duties of all employees.

2. To consider questions referred to it and make recommendations regarding the initiation of projects concerning the erection or alteration of laboratories and offices.

3. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

4. To supervise such construction and equipment work as may be authorized by the executive committee.

##### ORGANIZATION

Dr. Joseph S. Ames, chairman.

Dr. David W. Taylor, vice chairman.

Prof. Charles F. Marvin.

John F. Victory, secretary.

#### COMMITTEE ON GOVERNMENTAL RELATIONS

##### FUNCTIONS

1. Relations of the committee with executive departments and other branches of the Government.

2. Governmental relations with civil agencies.

##### ORGANIZATION

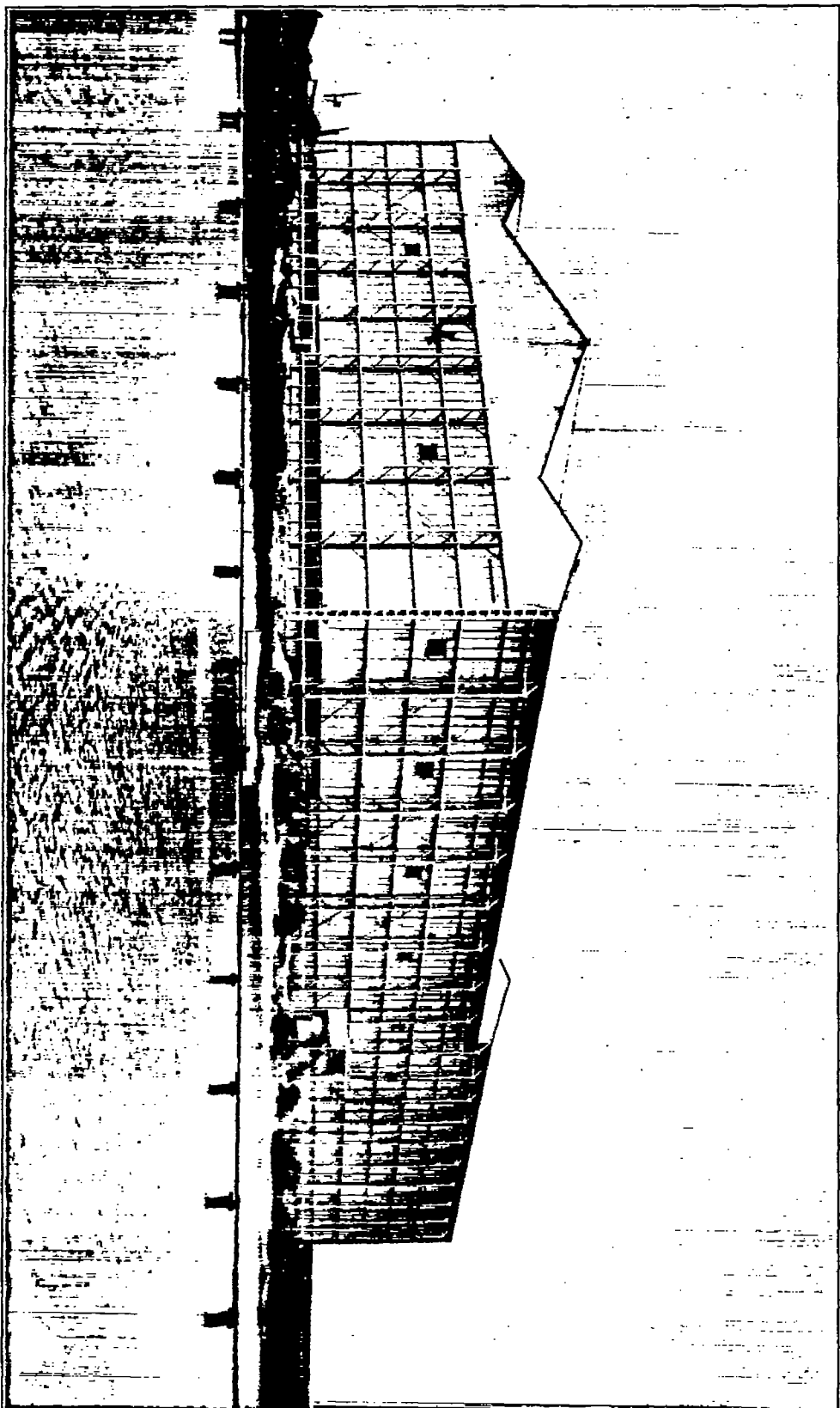
Prof. Charles F. Marvin, chairman.

Dr. David W. Taylor.

John F. Victory, secretary.

#### QUARTERS FOR COMMITTEE

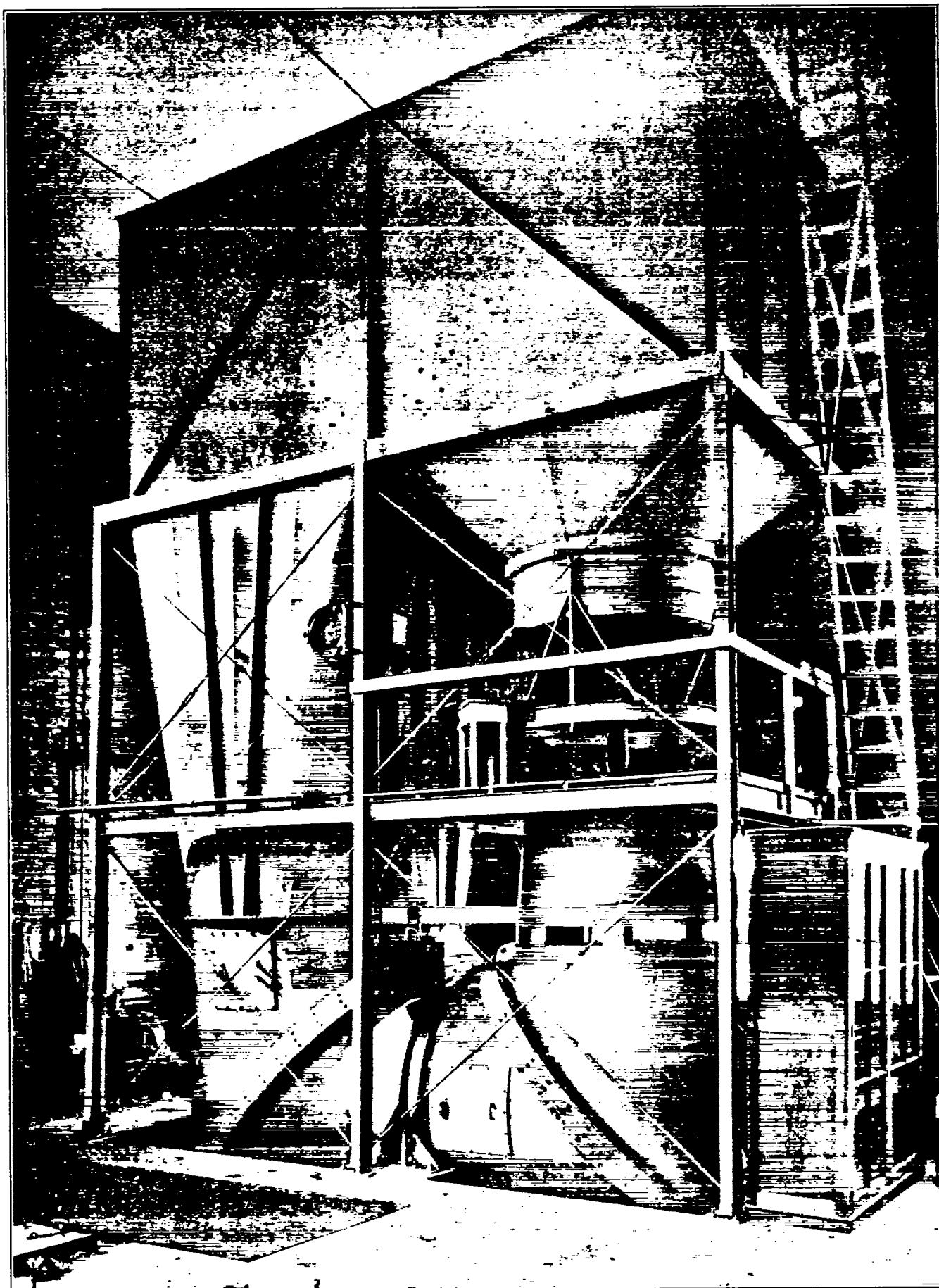
The headquarters of the National Advisory Committee for Aeronautics are located at the rear of the eighth wing, third floor of the Navy Building, Eighteenth and B Streets NW., Washington, D. C.



EXTERIOR VIEW, FULL SCALE WIND TUNNEL  
FOR TESTING FULL SIZED AIRPLANES IN AN AIR STREAM AT VELOCITIES UP TO 110 MILES PER HOUR



INTERIOR VIEW, SEAPLANE TOWING CHANNEL, NOVEMBER 1, 1930  
SHOWING TOWING CARRIAGE RAILS IN PLACE AND WATER IN TANK, 2,050 FEET LONG  
NOTE REFLECTION IN THE WATER OF ROOF CONSTRUCTION



THE VERTICAL WIND TUNNEL  
FOR INVESTIGATION OF SPINNING CHARACTERISTICS OF AIRPLANES

in close proximity to the Army and Navy air organizations. This space has been officially assigned for use of the committee by the Public Buildings Commission. The administrative office is also the headquarters of the various subcommittees and of the Office of Aeronautical Intelligence. Through the cooperation of the War Department and of the Shipping Board, and with the approval of the Public Buildings Commission, an additional 1,520 square feet of office space in the Navy Building was made available to the committee in October, 1930. This has given temporary relief from a condition of congestion which had impaired the efficiency of the organization. This additional space makes a present total of 8,914 square feet of office space occupied by the committee in Washington, and will enable the committee for a time to discharge its functions more effectively.

Field stations of the committee are the Langley Memorial Aeronautical Laboratory, Langley Field, Hampton, Va., and the office of the technical assistant in Europe, located at the American Embassy in Paris.

The scientific investigations authorized by the committee are not all conducted at the Langley Memorial Aeronautical Laboratory, but the facilities of other governmental laboratories are utilized as well as the laboratories connected with institutions of learning whose cooperation in the scientific study of specific problems in aeronautics has been secured.

#### THE LANGLEY MEMORIAL AERONAUTICAL LABORATORY

The Langley Memorial Aeronautical Laboratory is operated under the direct control of the committee. It is located at Langley Field, Va., on a plot of ground set aside by the War Department for the committee's use. The laboratory was started in 1916 coincident with the establishment of Langley Field.

The laboratory is organized with six divisions, as follows: Aerodynamics division, power plants division, technical service division, flight operations division, property and clerical division, and a new hydrodynamics division. The laboratory is under the immediate direction of an engineer in charge, Mr. Henry J. E. Reid, subject to the general supervision of the officers of the committee.

During the past year work was begun and substantial progress was made in the construction of the full-scale wind tunnel and of the seaplane channel. The new wind tunnel when completed will have an oval-shaped throat 60 by 30 feet, which will permit the testing of full-sized airplanes. It is expected that this tunnel will be in operation during the summer of 1931. The photograph taken November 1, 1930, and reproduced herewith shows the character of the external structure.

The new seaplane channel will be 2,050 feet long and it is expected it will be ready for the testing of seaplane floats and flying-boat hulls during the summer of 1931. This is the first equipment of this character that has ever been constructed, and is solely for the purpose of investigating the characteristics of seaplane floats and boats. The great length of the channel is necessary to provide for the high speed which is required for tests of this character.

The construction of a new permanent brick hangar with repair shop and facilities for taking care of airplanes used in flight, recently authorized by Congress, will be started in the spring of 1931.

The War Department has assigned to the committee additional space on a suitable part of Langley Field for the erection of the full-scale wind tunnel, for the seaplane channel, and for the new hangar to replace the present steel hangar, which must be removed to make way for extensive military improvements to the field.

There are at present nine structures comprising the Langley Memorial Aeronautical Laboratory, which, with the two additional structures to be completed during the fiscal year 1931, will make a total of 11 structures, as follows:

1. A research laboratory building containing administrative offices, technical library, physics laboratory, photographic laboratory, and headquarters of the various divisions.

2. An atmospheric wind-tunnel building, in which the 5-foot wind tunnel of a standard closed-throat type has been replaced by more modern equipment. In the space formerly required by the 5-foot tunnel has been built a modern closed-return tunnel with an open rectangular throat 7 by 10 feet, and a vertical tunnel with closed return and an open throat 5 feet in diameter. These two pieces of equipment are to be used in a comprehensive study of the problems of control and spinning characteristics of an airplane. In addition to the above equipment the building now houses a 6-inch open-throat wind tunnel for instrument and wind-tunnel studies, and a 6-inch refrigerated tunnel for the study of ice formation on aircraft. More efficient use of space has also provided room for a workshop and office for the staff operating the tunnels.

3. A variable-density wind-tunnel building, housing the variable-density wind tunnel and a jet-type high-speed wind tunnel which utilizes the waste air from the variable-density wind tunnel.

- 4 and 5. Two engine dynamometer laboratories of a semipermanent type equipped to carry on investigations in connection with power plants for aircraft. In addition to the usual dynamometer equipment and single-cylinder test engines for studying both carbureted and Diesel oil engines, there is equipment



sued to the study of superchargers and the cooling of engine cylinders, and to the study of fuel sprays by means of special high-speed photographic equipment.

6. A service building containing an instrument laboratory, drafting room, machine shop, woodworking shop, and storeroom.

7. A propeller research tunnel, in which tests may be made in a 20-foot air stream at 100 miles per hour. This equipment permits the full-scale testing of propellers, fuselages, and landing gears.

8. An airplane hangar with a repair shop and facilities for taking care of airplanes used in flight research. This will be replaced by a new hangar, as stated above.

9. A combination heating plant, storehouse, and garage.

10. A new full-scale wind tunnel, described above.

11. A new seaplane channel, described above.

Items 1, 2, 3, 4, 5, 6, and 9 are located on plot 16. Items 7, 10, and 11 are located within two blocks of the laboratory headquarters, and item 8 is located on the flying field.

Recognition by the Government of the necessity of satisfying the increasing demand for new and accurate knowledge on the fundamental problems of flight has made possible the development of the Langley Memorial Aeronautical Laboratory as an efficient research organization numbering 211 employees at the close of the fiscal year 1930. The work of the laboratory is conducted without interference with military operations at the field. In fact, there is a splendid spirit of cooperation on the part of the military authorities, who by their helpfulness in many ways have aided the committee materially in its work.

#### THE OFFICE OF AERONAUTICAL INTELLIGENCE

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral branch of the committee's activities. Its functions are the collection, classification, and diffusion of technical knowledge on the subject of aeronautics, including the results of research and experimental work conducted in all parts of the world, to the military and naval air organizations, aircraft manufacturers, educational institutions, and others interested. It is the officially designated Government depository for scientific and technical reports and data on aeronautics.

Promptly upon receipt, all reports are analyzed, classified, and brought to the special attention of the subcommittees having cognizance and to the attention of other interested parties through the medium of public and confidential bulletins. Reports are duplicated where practicable and distributed upon request.

Confidential bulletins and reports are not circulated outside of Government channels.

The records of the committee show that there has been a continuous increase in the distribution of technical publications. During the year 14,984 written requests for reports were received in addition to a large number of telephone and personal requests and 76,262 reports were distributed upon request.

The technical publications were distributed as follows:

Committee and subcommittee members	2,852
Langley Memorial Aeronautical Laboratory	2,065
Paris office of the committee	6,341
Army Air Corps	2,036
Naval Air Service, including Marine Corps	8,750
Manufacturers	20,974
Educational institutions	14,708
Bureau of Standards	618
Miscellaneous	57,166
Total distribution	112,010

The above figures include the distribution of 38,735 Technical Reports, 19,735 Technical Notes, 82,086 Technical Memorandums, and 10,919 Aircraft Circulars of the National Advisory Committee for Aeronautics. Part IV of this report presents the titles of the publications issued during the past year, the distribution of which is included in the foregoing figures.

To handle efficiently the work of securing and exchanging reports in foreign countries, the committee maintains a technical assistant in Europe, with headquarters at the American Embassy in Paris. It is his duty to visit the government and private laboratories, centers of aeronautical information, and private individuals in England, France, Italy, Germany, and other European countries and endeavor to secure for America not only printed matter which would in the ordinary course of events become available in this country but more especially advance information as to work in progress and technical data not prepared in printed form, which would otherwise not reach this country. John Jay Ide, of New York, has served as the committee's technical assistant in Europe since April, 1921.

#### FINANCIAL REPORT

The appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1930, as carried in the independent offices appropriation act approved February 20, 1929, was \$1,277,200. Of this amount, \$5,000 was later transferred to the appropriation for printing and binding, fiscal year 1930, by first deficiency act, fiscal year 1930, approved March 26, 1930, to provide funds for the increasingly large

number of Technical Reports being issued by the committee, leaving a balance of \$1,272,200 in the regular appropriation. In addition, the sum of \$208,000 was made available for the fiscal years 1929 and 1930 by second deficiency act, fiscal year 1929, approved March 4, 1929, for the construction of a seaplane channel, making the total appropriation for 1930 in effect \$1,488,000, under which the committee reports expenditures and obligations during the year amounting to \$1,477,984.73, itemized as follows:

Personal services.....	\$582,263.13
Supplies and materials.....	37,596.00
Communication service.....	1,481.48
Travel expenses.....	15,129.59
Transportation of things.....	729.22
Furnishing of electricity.....	10,443.48
Rent of office (Paris).....	960.00
Repairs and alterations.....	5,474.90

Special investigations and reports.....	\$46,500.00
Equipment.....	800,349.30
Structures and parts.....	27,055.68
Expenditures.....	1,477,984.73
Unobligated balance.....	10,015.27
Total.....	1,488,000.00

The appropriation for printing and binding for 1930 as carried in the independent offices act approved February 20, 1929, was \$15,000, which, with the \$5,000 transferred from the regular appropriation, made available the amount of \$20,000, out of which \$19,996.65 was expended.

The appropriations for the fiscal year 1931 total \$1,321,000, which includes \$375,000 for the completion of the full-scale wind tunnel and \$60,000 for the construction of a hangar.

## PART II

### GENERAL ACTIVITIES

#### STUDY OF AIRCRAFT ACCIDENTS

In response to request of the Air Coordination Committee, consisting of the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce, the National Advisory Committee for Aeronautics organized, in March, 1928, a special committee on the nomenclature, subdivision, and classification of aircraft accidents, to prepare a basis for the classification and comparison of aircraft accidents, both civil and military. This committee made a detailed study of the problem, and as a result drew up a chart for the analysis of accidents, combining consideration of the immediate causes, underlying causes, and results of accidents. This chart, together with a detailed explanation, was published in October, 1928, as Technical Report No. 308 of the National Advisory Committee for Aeronautics, entitled "Aircraft Accidents—Methods of Analysis," and was officially adopted for use by the War, Navy, and Commerce Departments.

On completion of this report the special committee on the nomenclature, subdivision, and classification of aircraft accidents was discharged, and a new standing committee on aircraft accidents was appointed with the same personnel as the special committee, to consider from time to time questions which might arise as to the interpretation of the method of analysis and suggestions as to changes, to study the information obtained from the accident analysis, and to discuss such other problems relating to aircraft accidents as might appear desirable or as might be brought before it.

The present membership of the committee on aircraft accidents is as follows:

- Dr. George K. Burgess, Bureau of Standards, chairman.
- Lieut. Harold Brand, United States Army Air Corps.
- George W. Lewis, National Advisory Committee for Aeronautics.
- W. Fiske Marshall, Aeronautics Branch, Department of Commerce.
- Lieut. Commander Frank D. Wagner, United States Navy, Bureau of Aeronautics.

Lieut. Frank T. Ward, United States Navy, Bureau of Aeronautics.

Hon. Edward P. Warner, editor of "Aviation."

Lieut. Lyman P. Whitten, United States Army Air Corps.

The initial meeting of the committee on aircraft accidents was held in March, 1929, for the purpose of studying the personnel factor in aircraft accidents. Analyses of aircraft accidents by the War, Navy, and Commerce Departments indicated that about 50 per cent were chargeable to errors of the pilot, and it seemed desirable that this phase of the problem be given careful study. Representatives of the medical personnel of the naval flying service, the Army Air Corps, and the Aeronautics Branch of the Department of Commerce were invited to attend this meeting, as well as subsequent meetings, and assisted in the discussion, in order that the physiological and psychological reactions of the pilot might be given adequate consideration.

In connection with the discussion of the problem of personnel in relation to accidents it was agreed that practical experience with the analysis chart and definitions in Report No. 308 showed the need for clarification of a number of the definitions. The committee accordingly undertook a revision of this report.

Statistical information was presented by the representatives of the three air organizations, respectively, indicating a number of important facts with regard to the accidents problem.

One of the most important of these facts was that there is a definite relation between the accident rates of groups of pilots on the one hand and the average total flying experience and average annual flying practice of those pilots on the other. Other information of importance which these statistics revealed was the fact that a very large percentage of spins and stalls result fatally; that "poor reaction" on the part of the pilot is a frequent underlying cause of accidents; and that in one group of accidents covering a considerable period of time the pilots who had been involved in fatal accidents had, in the preceding year or two, had about three times as many accidents of a minor character as other pilots, indicating the desirability of dis-

qualifying pilots who have a series of minor accidents at short intervals.

All these phases of the accident problem were given careful consideration in the meetings of the committee, and while no definite recommendations as to the physiological and psychological questions were made by the committee, it is believed that the discussions of these questions in the meetings have been of considerable value to the representatives of the three services in their study of the accidents problem in their respective organizations.

The committee is greatly indebted for valuable assistance to the following former members, who have since been relieved from membership upon their resignation or transfer to duty outside of Washington:

Lieut. J. D. Barker, United States Army.  
Lieut. Charles R. Brown, United States Navy.  
Edward P. Howard, Aeronautics Branch, Department of Commerce.  
Lieut. D. B. Phillips, United States Army.  
Lieut. Commander L. C. Stevens, United States Navy.

The following representatives from the Government organizations concerned have also contributed greatly to the work of the committee:

Dr. L. H. Bauer, Aeronautics Branch, Department of Commerce.  
Dr. H. J. Cooper, Aeronautics Branch, Department of Commerce.  
Commander R. G. Davis (M. C.), United States Navy.  
P. Edgar, Aeronautics Branch, Department of Commerce.  
Lieut. Col. L. M. Hathaway (M. C.), United States Army.  
F. J. Martel, Aeronautics Branch, Department of Commerce.  
Lieut. Commander John R. Poppen (M. C.), United States Navy.  
E. R. Strong, Aeronautics Branch, Department of Commerce.  
Starr Truscott, National Advisory Committee for Aeronautics.

The revision of Report No. 308 has been completed during the past year and published as Technical Report No. 357, "Aircraft Accidents—Methods of Analysis," superseding the earlier report. The revised report includes, in addition to the accident analysis chart and definitions prepared by the special committee with a number of the definitions clarified, a brief statement of the organization and work of the special committee and of the committee on aircraft accidents and statistical tables giving a comparison of the types

of accidents and causes of accidents in the military services on the one hand and in civil aviation on the other, together with explanations of some of the important differences noted in these tables.

#### CONSIDERATION OF AERONAUTICAL INVENTIONS

By act of Congress approved July 2, 1926, a Patents and Design Board was created, and it was provided that upon recommendation of the National Advisory Committee for Aeronautics the board should determine questions as to the use and value to the Government of aeronautical inventions submitted to the Government. By act of Congress approved March 3, 1927, the act of July 2, 1926, was amended in such a manner as to limit the board to the consideration of such cases as were favorably recommended to it by the National Advisory Committee for Aeronautics. This relieved the board of the burden of considering cases which were unfavorably recommended by the committee, but at the same time it made the National Advisory Committee for Aeronautics responsible for the final disapproval of the large majority of the devices submitted as applications for awards.

In order to discharge the duties devolving upon the committee under this legislation a committee on aeronautical inventions and designs was created, the present membership of which is as follows:

Dr. D. W. Taylor, chairman.  
Dr. George K. Burgess, vice chairman.  
Prof. Charles F. Marvin.  
Capt. John H. Towers, United States Navy.  
J. F. Victory, secretary.

Inventions and designs submitted are considered by the Director of Aeronautical Research. The committee on aeronautical inventions or designs considers only such inventions or designs as are presented by the Director of Aeronautical Research or are recommended for committee consideration by any other member of the National Advisory Committee. The Director of Aeronautical Research is authorized to submit his unfavorable recommendations direct to the Aeronautical Patents and Design Board, but any favorable recommendation must be considered and made by the committee on aeronautical inventions and designs.

Under the present procedure careful consideration is given to all inventions and designs submitted. The Aeronautical Patents and design Board and the National Advisory Committee for Aeronautics are working in harmony and the burden of considering large numbers of invention is placed so as to reduce the demands on the time of the members of the committee on aeronautical inventions and designs and of the members of the Aeronautical Patents and Design Board

to the consideration of submissions which have received competent preliminary examination and are deemed worthy of further consideration.

The Aeronautical Patents and Design Board has been in operation four years. During the past year the National Advisory Committee for Aeronautics has received a little over 2,200 letters relating to inventions. Approximately 1,000 of these represented new submissions. The majority of these cases, being addressed to the committee, were acted on by direct correspondence with the submitters. In 97 cases which were submitted to the Aeronautical Patents and Design Board the committee prepared individual reports as to the merits of the particular invention or design for the action of the board.

#### RELATIONS WITH THE AIRCRAFT INDUSTRY

In 1926 the National Advisory Committee for Aeronautics established the policy of holding at its laboratory at Langley Field, the Langley Memorial Aeronautical Laboratory, annual conferences with representatives of the manufacturers and operators of aircraft. The purpose of these conferences was to give to aircraft manufacturers and operators an opportunity to become acquainted with the facilities for aeronautical research at the committee's laboratory and also to afford them an opportunity to make suggestions to the committee as to aeronautical research problems of interest to the industry which in their opinion the committee is especially equipped to solve.

In accordance with this policy, the Fifth Annual Aircraft Engineering Research Conference was held at the committee's laboratory on May 13, 1930. The committee was represented by its officers, members of the main committee, and the members of its committees on aerodynamics and power plants for aircraft. The conference was presided over by Dr. Joseph S. Ames, chairman of the National Advisory Committee for Aeronautics.

At the morning session the principal investigations under way at the laboratory, both in aerodynamics and power plants, were explained by the engineers in charge of the work, and charts were exhibited showing some of the results obtained.

Among the more important aerodynamic investigations outlined were the determination in the 20-foot propeller research tunnel of the drag of various parts of a cabin monoplane; study in the propeller research tunnel of the interference effects between an engine nacelle with N. A. C. A. cowling, propeller, and wing; determination of the effect of a locked or idling propeller on the lift of a wing; investigation of the interference effects between wing, fuselage, and landing gear in various monoplane combinations; study of the effect of fillets between wing and fuselage on a low-

wing monoplane; study in the atmospheric wind tunnel of the pressure distribution over a wing with different degrees of twist; determination in flight of the pressure distribution over the wings of a Douglas mail airplane; study of the water-pressure distribution on seaplane hulls in landing; investigation in the propeller research tunnel of a typical metal propeller over a large range of pitches and with various typical combinations of fuselages and engines; study of the spinning characteristics of airplanes, including the aerodynamic forces and couples and the inertia forces and couples as principal factors in the spinning problem; determination of the effect of various modifications of the N. A. C. A. cowling on performance, aerodynamic characteristics, and engine temperatures.

The principal power-plant projects described were those relating to the development of a fuel-injection type of engine for aircraft, and to the development of aircraft engine superchargers. Among the fuel-injection investigations were the effect of the position of the injection valve stem on the coefficient of discharge; the effect of orifice-length diameter ratio on fuel spray penetration; method for the determination of instantaneous pressures obtained in the fuel-injection line during a single injection cycle; and study of the design of combustion chamber for obtaining proper distribution of fuel in the cylinder of an aircraft Diesel type engine. The supercharger investigations included the determination of the characteristics of the Roots type supercharger and a study of the comparative flight performance of the Roots type and the exhaust-driven turbocentrifugal type supercharger.

At the close of the session, the representatives of the industry were conducted on a tour of inspection of the committee's laboratories, and the research equipment was shown in operation.

The afternoon session was devoted to the discussion of the problems of commercial aeronautics, and 22 suggestions as to investigations to be conducted by the committee were made, chiefly by representatives of the industry. Many of these problems were already a part of the committee's research program. Among the problems discussed were the shape of the fuselage as affected by the wing and engine location; the position of the engines in multi-engined biplanes and monoplanes; study of the air flow over an airplane in flight; investigation of the mass distribution of the airplane; investigation of the sources of noise in aircraft; investigation of jet propulsion.

The 22 suggestions presented at the conference have since been carefully considered by the committee on aerodynamics or the committee on power plants for aircraft, and three of them—the study of the cowling and interference of engines in tandem, the investigation of the sources of noise in aircraft, and the study

of jet propulsion—have since been added to the committee's program of research, the first two for investigation at the Langley Memorial Aeronautical Laboratory and the third at the Bureau of Standards.

#### COOPERATION OF ARMY AND NAVY

Through the personal contact of the heads of the Army and Navy air organizations serving on the main committee and the frequent personal contact on the subcommittees of their chief subordinates who have to do with technical matters in aeronautics, there has been accomplished in fact not only a coordination of aeronautical research, which is the major function of the committee, but also a coordination of experimental engineering activities of the services and an exchange of first-hand information, comment, and suggestions that have had beneficial effects in both services. The needs of each service in the field of aeronautical research are discussed and agreements invariably reached that promote the public interests. The cordial relations that usually follow from frequent personal contact are supplemented by the technical information service of the committee's Office of Aeronautical Intelligence, which makes available the latest scientific data and technical information secured from all parts of the world. Although there is a healthy rivalry between the Army and Navy air organizations, there is at the same time a spirit of cooperation and a mutual understanding of each other's problems that serve to prevent unnecessary duplication in technical developments in aeronautics.

Much of the fundamental research work of the committee has grown out of requests received from the Army and Navy for the study by the committee of particular problems encountered in the services, and in connection with this work the committee desires to give special recognition to the splendid spirit of cooperation of the two services with the committee. Both services have placed at the disposal of the committee airplanes and engines required for research purposes and have otherwise aided in every practical way in the conduct of scientific investigations by the committee. Without this cooperation the committee could not have prosecuted successfully many of its investigations that have made for progress in aircraft development. The committee desires especially to acknowledge the many courtesies extended by the Army authorities at Langley Field, where the committee's laboratories are located, and by the naval authorities at the Hampton Roads Naval Air Station.

#### INVESTIGATIONS UNDERTAKEN FOR THE ARMY AND THE NAVY

As a rule research programs covering fundamental problems demanding solution are prepared by the tech-

nical subcommittees and recommended to the executive committee for approval. These programs supply the problems for investigation by the Langley Memorial Aeronautical Laboratory. When, however, the Army Air Corps, the Naval Bureau of Aeronautics, or the Aeronautics Branch of the Department of Commerce desires special investigations to be undertaken by the committee, such investigations, upon approval by the executive committee, are added to the current research programs.

The investigations thus under conduct by the committee during the past year for the Army and the Navy may be outlined as follows:

##### FOR THE AIR CORPS OF THE ARMY

- Investigation of pressure distribution and accelerations on pursuit-type airplanes.
- Acceleration readings on the *PW-9* airplane.
- Investigation of pressure distribution on observation-type airplane.
- Investigation of tail-surface loads in maneuvers.
- Wind-tunnel investigation of biplane cellules.
- Study of ice formation.
- Investigation of velocity distribution in plane of propeller disk.
- Investigation of cowling for protection of gunners and pilots from air currents.
- Determination of moment coefficients and hinge moment coefficients for different tail surfaces.
- Determination of aileron hinge moments versus rolling moments for various types of ailerons and wings.
- Investigation of wing flutter.
- Investigation of the flat spin.

##### FOR THE BUREAU OF AERONAUTICS OF THE NAVY DEPARTMENT

- Investigation of water-pressure distribution on seaplane hulls.
- Investigation of the forces on seaplane floats under landing conditions.
- Comparative tests of rubber and oleo type landing gears.
- Investigation of aerodynamic loads on the U. S. S. *Los Angeles*.
- Deceleration tests on the metal-clad airship *ZMC-2*.
- Study of design factors for metal propellers.
- Investigation of methods of improving wing characteristics by control of the "boundary layer."
- Ice formation on aircraft.
- Investigation of comparative aerodynamic resistance of riveted and bolted construction.
- Investigation of effect of sags in wing surface.
- Investigation of windshields and fairings for protection from air currents.

- Investigation of flight-path characteristics.
- Investigation of autorotation.
- Development of solid-injection type of aeronautical engine.
- Investigation of application of compression ignition to air-cooled engine cylinders.
- Development of aircraft engine supercharger.
- Effect of supercharging highly heated inlet air on performance of carburetor type engine.
- Study of effect of different degrees of supercharging with several compression ratios.

#### COOPERATION WITH STATE DEPARTMENT ABROAD

The committee has cooperated with the Department of State by making available the services of its technical assistant in Europe, Mr. John J. Ide, for attendance as unofficial observer or technical adviser on behalf of the United States at several international air conferences abroad. Acting under special authorization of the State Department in each case, Mr. Ide represented the United States unofficially at the Ninth Congress of the Comité-Juridique International de l'Aviation at Budapest, Hungary, September 29 to October 3, 1930, and the sixth session of the International Technical Committee of Aeronautical Juridical Experts at Budapest beginning October 6. Mr. Ide has also been designated by the Department of State a delegate on the part of the United States to the First International Congress on Aerial Safety to be held at Paris December 10 to 23, 1930.

#### THE DANIEL GUGGENHEIM FUND FOR THE PROMOTION OF AERONAUTICS

The Daniel Guggenheim Fund for the Promotion of Aeronautics, organized in January, 1926, with deeds of gift totaling \$2,500,000 from the late Mr. Daniel Guggenheim, terminated its existence as of February 1, 1930. Thanks to the inspiration of Mr. Guggenheim and his leadership, the fund was one of the most important factors in accelerating the development of aviation during the years 1926 to 1929, and American aeronautics is greatly indebted to him. The purposes of the fund were to promote aeronautical education throughout the country, to assist in the extension of aeronautical science, and to further the development of commercial aircraft. During its four years of activity the character of its work changed to meet the changing needs of aviation.

The relations between the Guggenheim Fund and the National Advisory Committee for Aeronautics have always been cordial, and were strengthened in 1929 by the appointment of Mr. Harry F. Guggenheim, president of the fund, as one of the three additional members of the committee authorized by act of Congress approved March 2, 1929.

The work of the Guggenheim Fund in the field of education in aeronautical engineering has been outstanding. Financial assistance has been given to the Massachusetts Institute of Technology, the Georgia School of Technology, the California Institute of Technology, the University of Washington, Leland Stanford University, the Harvard University Graduate School of Business, and the University of Michigan for instruction and experiment in aeronautical engineering. Mr. Daniel Guggenheim had previously established the Daniel Guggenheim School of Aeronautics at New York University. In addition, the fund has established an airship institute at Akron, Ohio, under the joint direction of the city of Akron and the California Institute of Technology, and has made a grant for equipment and instruments to Syracuse University for special courses in aerial photographic surveying and mapping. The fund has also organized a committee on elementary and secondary aeronautical education.

The Guggenheim Fund made a contribution endowing in part the Guggenheim chair of aeronautics at the Library of Congress for the organization of a complete aeronautical library. This post is filled by Dr. A. F. Zahm. The Guggenheim Fund also made provision for the preparation of an encyclopedia of aerodynamic theory and experimentation under the direction of Dr. W. F. Durand. In recognition of the efforts of the National Aeronautical Association, the Guggenheim Fund made contributions to that patriotic organization's work in the promotion of private flying. Other important undertakings of the fund were to demonstrate a method of safe fog flying, by means of special instruments; to study the penetration of light through fog; and to develop a rubber "overshoe" for the prevention of ice formation on an airplane in flight.

In order to assist in the promotion of safety in aircraft the Guggenheim Fund conducted a safe-aircraft competition, which was announced on April 20, 1927, and closed on October 31, 1929. Twenty-seven entries of airplanes were received, but only 10 actually underwent tests for the competition, and of these only 2, the Curtiss *Tanager* and the Handley Page slotted-wing airplane, successfully passed the qualifying tests and were subjected to the final safety demonstrations. The competition was won by the Curtiss *Tanager*, and the prize was awarded on January 6, 1930. It is believed that the safety features demonstrated by the competition will be of value in the further development of airplane design.

#### COOPERATION WITH BRITISH AERONAUTICAL RESEARCH COMMITTEE

The cooperation which has been maintained for a number of years between the British Aeronautical Re-

search Committee and the National Advisory Committee for Aeronautics has been continued during the past year. Doctor Ames, chairman of this committee, visited Europe during the summer of 1930, and at that time discussed with the British committee many of the more important problems of aeronautical research. He also visited the various laboratories in which investigations are being conducted under the direction of the Aeronautical Research Committee, thus obtaining first-hand information on their activities. One of the members of the Aeronautical Research Committee, Prof. G. I. Taylor, visited the Langley Memorial Aeronautical Laboratory in October, 1929, where he saw the work in progress and offered a number of helpful suggestions.

At the suggestion of the British Air Ministry, arrangements were made in 1928 for an exchange of instruments used in flight research for comparison of the results of flight tests conducted by the British committee and our committee. In accordance with these arrangements, the committee tested at Langley Field a force-recording rudder bar and a force-recording control stick received from Great Britain, and forwarded to Great Britain in exchange a 3-component recording accelerometer. The report on the tests made at the Royal Aircraft Establishment on the N. A. C. A. accelerometer indicated a very favorable comparison of this instrument, both in calibrations and in flight tests in a Hawker Hornbill airplane, with the R. A. E. accelerometer, the maximum error noted being only 2 per cent.

The British committee has manifested considerable interest in the research equipment at the Langley Memorial Aeronautical Laboratory. The variable-density wind tunnel has proved of special value in the study of scale effect, and the Aeronautical Research Committee is now engaged in the construction of a wind tunnel of this type. The British committee is also contemplating the construction of a full-scale wind tunnel, realizing the value of such a tunnel in cases where full-scale results are important and actual flight tests would be particularly difficult or expensive. In connection with these projects, this committee has cooperated by supplying information as to details of construction and operation.

During the past year this committee completed in its variable-density wind tunnel tests conducted at the request of the British committee on models supplied by that committee, of the A. D. 1 wing section and of a Hawker Hornbill airplane using this wing section. These tests were made for comparison with the results of British wind-tunnel tests and of flight tests conducted at Farnborough on the full-sized airplane, in which unusual stability and control characteristics had been noted at high angles of attack. The report on these tests has been forwarded to England, and will

be published by the British committee. These tests show fairly close agreement with the flight test results as to the lift coefficients of the wing, and give further evidence of the unusually high stability and control characteristics of this airfoil section at low speeds.

#### EXHIBIT AT SEVILLE INTERNATIONAL EXPOSITION

Upon invitation of Hon. Thomas E. Campbell, commissioner general, Commission of the United States of America, the International Exposition at Seville, Spain, the National Advisory Committee for Aeronautics entered an exhibit as a part of a comprehensive exhibit entered by the Government of the United States in the exposition at Seville. The cost was defrayed from a special appropriation made by the Congress for participation of the Government of the United States.

New working models of the variable-density wind tunnel and of the propeller research tunnel were constructed from funds allotted to the committee by the commissioner general. Arrangements for the committee's exhibit were under the direction of Mr. John F. Victory, secretary of the committee, who served as contact officer for the exposition. Mr. Chester W. Hicks, assistant mechanical engineer at the committee's laboratory at Langley Field, Va., was detailed for special duty at Seville, in connection with the installation, maintenance, explanation, and return of the committee's exhibit.

The exposition opened May 9, 1929, and closed June 21, 1930. In addition to the two working models mentioned above a selection for the Seville exposition was made from the exhibits prepared by the committee for the Sesquicentennial Exposition at Philadelphia in 1926. The committee's exhibit comprised five working models, one show case containing airplane models and aeronautical instruments, a set of models showing in relief the pressure distribution on the surfaces of airplanes and of airships, and 18 charts showing the methods of conducting various investigations with the unique research equipment at the committee's laboratories. The five working models were: (1) The control system of an airplane; (2) why an airplane flies—a physical demonstration of the variation of lift along the chord of an airplane wing showing also the difference in lift of the upper and under surfaces of the same wing; (3) the variable-density wind tunnel; (4) the propeller-research tunnel; (5) a model showing the effect of a rotating cylinder in an air stream and illustrating the principle involved in the Flettner rotor ship.

Reports received indicate that the Spanish public and visitors to Seville from many nations, including the United States, were interested in the demonstrations of equipment and methods used by the committee in the conduct of aeronautical research, and were



pleased with the exhibit as a whole. Sufficient data were included to make the exhibit of interest also to technically trained visitors, and particularly to those connected with aeronautical activities.

Upon the termination of the exposition the National Advisory Committee for Aeronautics was awarded a grand prize, and diplomas of honor were awarded the

Langley Memorial Aeronautical Laboratory, Mr. John F. Victory, contact officer, and Mr. Chester W. Hicks, representative of the committee in charge of its exhibit in Spain. Upon return of the committee's exhibit to Washington it was reinstalled in the National Academy of Sciences Building, where it is available for inspection of the public.

## PART III

### REPORTS OF TECHNICAL COMMITTEES

#### REPORT OF COMMITTEE ON AERODYNAMICS

##### ORGANIZATION

The committee on aerodynamics is at present composed of the following members:

Dr. David W. Taylor, chairman.  
Dr. L. J. Briggs, Bureau of Standards.  
G. G. Budwig, Aeronautics Branch, Department of Commerce.  
Lieut. W. S. Diehl (C. C.), United States Navy.  
Lieut. Albert C. Foulk, United States Army, matériel division, Air Corps, Wright Field.  
Maj. C. W. Howard, United States Army, matériel division, Air Corps, Wright Field.  
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).  
Prof. Charles F. Marvin, Weather Bureau.  
Lieut. Commander A. C. Miles (C. C.), United States Navy.  
Hon. Edward P. Warner, editor of "Aviation."  
Dr. A. F. Zahn, Division of Aeronautics, Library of Congress.

##### FUNCTIONS

The functions of the committee on aerodynamics are as follows:

1. To determine what problems in theoretical and experimental aerodynamics are the most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding aerodynamic investigations and developments in progress or proposed.
4. To direct and conduct research in experimental aerodynamics in such laboratory or laboratories as may be placed either in whole or in part under its direction.
5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

The committee on aerodynamics, by reason of the representation of the various organizations interested in aeronautics, is in close contact with all aerodynamical work being carried out in the United States. The current work of each organization is therefore made known to all, duplication of effort being thus pre-

vented. Also all research work is stimulated by the prompt distribution of new ideas and new results, which add greatly to the efficient conduct of aerodynamic research. The committee keeps the research workers in this country supplied with information on European progress in aerodynamics by means of a foreign representative, who is in close touch with aeronautical activities in Europe. This direct information is supplemented by the translation and circulation of copies of the more important foreign reports and articles.

The committee on aerodynamics has direct control of the aerodynamical research conducted at Langley Field and of a number of special investigations conducted at the Bureau of Standards. The aerodynamical investigations undertaken at the Washington Navy Yard, the matériel division of the Army Air Corps at Wright Field, and the Bureau of Standards are reported to the committee on aerodynamics.

##### SUBCOMMITTEE ON AIRSHIPS

In order that the committee on aerodynamics may be kept in close touch with the latest developments in the field of airship design and construction and that research on lighter-than-air craft may be fostered and encouraged, a subcommittee on airships has been organized under the committee on aerodynamics, the membership of which is as follows:

Hon. Edward P. Warner, editor of "Aviation," chairman.  
Starr Truscott, National Advisory Committee for Aeronautics, vice chairman.  
Dr. Karl Arnstein, Goodyear-Zeppelin Corporation.  
Capt. Karl S. Axtater, United States Army, matériel division, Air Corps, Wright Field.  
Commander Garland Fulton (C. C.), United States Navy.  
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).  
Ralph H. Upson, Red Bank, N. J.

During the past year the subcommittee on airships has kept in touch with the progress of airship investigations on the program of the committee's laboratory at Langley Field. These investigations are the study of airship forms, and especially of airship

appendages, in the variable-density wind tunnel, including the determination of the drag, cross-wind forces, and moments at various angles of pitch and yaw and different rudder and elevator settings on a model of the *ZRS-4* airship; the investigation in the 20-foot wind tunnel of the effect of appendages on airship hulls, including tests of an airship model about 40 inches in diameter with various protrusions, such as water-recovery apparatus, cars, propeller mountings, fins, and rudders of different contours; the study of the forces on an airship entering a hangar, including the construction of models of two types of hangars and the measurement of the forces and moments on an airship model in various positions with respect to the hangar and the direction of the wind stream; and the investigation in flight of deceleration on the metal-clad airship *ZMC-2* to determine its drag characteristics.

As the subject of the structure of the atmosphere, especially vertical air currents and gustiness, is of particular importance in connection with the operation of arships, the subcommittee has continued its consideration of these problems with the cooperation of the subcommittee on meteorological problems of the committee on problems of air navigation.

#### SUBCOMMITTEE ON AERONAUTICAL RESEARCH IN UNIVERSITIES

In order to coordinate the aerodynamic research work undertaken by the various institutions of learning and to aid in improving the courses in aeronautical engineering and in promoting the study of aeronautics, a subcommittee on aeronautical research in universities has been organized under the committee on aerodynamics.

The membership of this subcommittee is as follows:

- Prof. Charles F. Marvin, Weather Bureau, chairman.
- Hon. Harry F. Guggenheim.
- Prof. Alexander Klemin, New York University.
- Prof. E. P. Lesley, Stanford University.
- George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
- Prof. Clark B. Millikan, California Institute of Technology.
- Prof. F. W. Pawlowski, University of Michigan.
- Prof. Richard H. Smith, Massachusetts Institute of Technology.

The functions of the subcommittee on aeronautical research in universities are as follows:

1. To consider aeronautical problems with a view to the initiation and conduct of aeronautical research by educational institutions, and in connection therewith to prepare programs of suggested lines of research intended to supplement existing research programs and to develop and train personnel for the

conduct of scientific research in aeronautics along original lines.

2. To seek through interchange of ideas to improve the courses in aeronautical engineering and to promote the study of aeronautics and aerology in educational institutions.

3. To meet from time to time on call of the chairman and to report its actions and recommendations to the committee on aerodynamics.

A meeting of the subcommittee on aeronautical research in universities was held at the Langley Memorial Aeronautical Laboratory on June 20, 1930. The topics under discussion at this meeting included the equipment, courses of study, and methods of teaching at educational institutions and the difficulty of securing satisfactory positions for the large number of students desiring to take courses in aeronautical engineering. In connection with the meeting the members of the subcommittee made a tour of inspection of the facilities and activities of the laboratory. There was discussion of the desirability of an arrangement whereby the National Advisory Committee, through its laboratory at Langley Field and other contacts, would suggest to the educational institutions relatively simple research problems that would be suitable for students' theses. It was agreed that consideration would be given during the current year to the formulation of a plan whereby more important researches could be undertaken by members of the staffs of the various educational institutions.

Investigations under way during the year at the various institutions represented on the subcommittee were described and discussed.

*California Institute of Technology.*—The work under way at the California Institute of Technology included the development of a special apparatus for the study of the flow in the boundary layer; investigation of thin sheets for monocoque fuselages; study of the application of the elastic theory in dealing with stability of monocoque structures; calibration in wind tunnels; investigation of compressible fluids at velocities above that of sound; study of the general theory of biplanes; and development of an analytical formula for the prediction of performance.

*Massachusetts Institute of Technology.*—At the Massachusetts Institute of Technology work has been conducted on the investigation of tail-plane loads, with a view to the development of a more satisfactory design load formula; investigation of the shear strength of duralumin sheets, in connection with monocoque fuselage construction; development of a hot-wire turbulence indicator; study of the comparative results of the Munk and Joukowski wing theories; and a new method for the determination of the three rotary coefficients on an airship or airplane.

*University of Michigan.*—Among the projects which have been under way at the University of Michigan are the design of a wind-tunnel balance especially for use in experiments with slotted wings; study of the buckling of thin plates in connection with monocoque fuselage design; study of the characteristics of horizontal stabilizing surfaces; and experiments with a model of a bridge truss to determine the effect of wind upon structures.

*New York University.*—At New York University work has been done on the investigation of wing lift characteristics; investigation of the interrelation between the aerodynamics and thermodynamics of air-cooled engines; investigation of airplane windshields; investigation of the Savonius rotor; and investigation of the ground handling of airships at an angle of 90° to the wind.

*Stanford University.*—The aerodynamic problems undertaken at Stanford University included an investigation of airplane landing speeds and an investigation of discontinuous air flow around simple quadric cylinders, while the following studies in aircraft structures have been carried on: Bending tests of metal monocoque fuselage construction; theoretical investigation of various methods of determining the torsional stresses in a box wing; and study of metal truss wing spars.

#### LANGLEY MEMORIAL AERONAUTICAL LABORATORY

*Stability and control.*—The problem of increasing the safety of aircraft continues to be of paramount importance, particularly in connection with commercial activities. Accident reports still indicate that the majority of accidents are connected with forced or bad landings and the tendency of airplanes to spin in the very attitude where they should be most easily controlled; i. e., at the low air speeds and high angles of attack likely to be experienced in forced landings. It is therefore evident that airplanes are too difficult to land, particularly in cases where the landing is forced. One of the greatest fields for increasing safety is, therefore, the improvement in stability and control throughout the entire possible range and the reduction of the space required for landing.

In connection with a program of research the aim of which is to increase the safety of aircraft, it became apparent that there was little definite knowledge of just what conventional present-day airplanes actually tend to do in situations which are thought to precede most accidents. The worst of these situations, it was generally agreed, are: (1) In an attempt to stretch a glide in a forced landing, the airplane is stalled, and (2) in a take-off, particularly a steep one, the engine fails suddenly at a low altitude. Simple flight tests on a wide variety of commercial and military airplanes

showed that the stalled glide, when combined with a slight turn, was in most cases followed by a spin. In the tests representing engine failure in a steep take-off, however, all of the airplanes which have neither very high wing loading nor very high drag could easily be put into a normal flat glide without loss of altitude. These tests therefore lead to the conclusion that by far the most dangerous situation is that of the stalled glide (which might also occur after engine failure in take-off), and emphasize the desirability for research on satisfactory stability and control up to the highest angles of attack which it is possible to obtain in flight.

A brief investigation has been made on an airplane in which the elevator control was limited to prevent stall and the effect on the performance was determined. Without any appreciable sacrifice in performance or controllability, it was found possible to limit the control so that an accidental stall during normal operation was impossible. However, by using considerable power it was still possible to stall deliberately. This work is to be continued on other airplanes.

A study has been made to establish the method of measurement necessary to evaluate the stability characteristics of an airplane, and a program has been drawn up for a flight investigation of both longitudinal and lateral stability and the factors affecting these, particularly at low speeds. The flight tests for this investigation are now in progress. Tests were completed in the atmospheric wind tunnel to determine the effect on stability of twisting a wing and the effect of change in profile along the span. Pressure distribution measurements were made on a wing of uniform section and one having a thick high-lift section at the root, changing to a thin section of the same chord at the tip. The changing section was found to decrease the maximum instability, and wash-out was found to have the same effect. The results of this work are being prepared for publication.

The results of an investigation of the pressure distribution over the surfaces of two airfoils arranged in various biplane combinations have been analyzed from the standpoint of lateral stability. It was found that stagger has the effect of decreasing the range and magnitude of maximum instability, and that decalage has a similar effect. A report on this work is in preparation.

*Spinning.*—Progress in the study of the spin problem has been greatly hindered in the past by a lack of quantitative knowledge of the motion of a spinning airplane. There has recently been developed a method by which all the physical quantities necessary for the complete determination of the flight path—motion, attitude, forces, and couples—of a fully developed spin can be made in flight. It is possible now to make changes to an airplane and measure the resulting

changes in its spinning characteristics, thus providing a direct solution of the question as to which factors most affect the spin. Using this method, an investigation has been made on one airplane in which the effect of change of mass distribution along the longitudinal axis and the change of longitudinal balance were studied. While the results of the work show that changes in either produced a definite change in certain of the spin characteristics, it was not possible with the changes permissible in this particular airplane to produce a dangerous spin. As a result, however, there has been made available a valuable fund of quantitative data on spins which should assist materially in the further study of the problem in the wind tunnel as well as in flight. The investigation is being continued on an airplane having initially much less satisfactory spinning characteristics. In this case changes of mass distribution about the three axes of the airplane are to be investigated, to be followed by changes of longitudinal balance and later by modifications of the control surfaces and in the geometric proportions of the airplane.

At the same time the method is being extended to include the measurements of the physical quantities necessary for complete determination of the elements of the entry into and recovery from the spin. In the spin investigations and likewise any of the dynamic conditions of flight, in order to compute the dynamic forces and couples occurring, it is necessary to know the mass characteristics of the airplane. For this reason the practice of measuring the moments and ellipsoids of inertia of all airplanes used in flight investigations has been continued. Accurate data have now been obtained on 12 airplanes. This information is being assembled for publishing for the information of others.

It has been known for some time that side slip is accompanied by a tendency to roll, but the extent of the rolling moment due to side slip was not appreciated until brought out by some recent tests made in the atmospheric wind tunnel, making use of an autorotation dynamometer. Four wing systems were tested at angles of yaw (or side slip) up to  $20^\circ$ , and it was found that in the normal autorotation range of angles of attack the rolling moments due to side slip of  $5^\circ$  to  $20^\circ$  were roughly of the same magnitude as those due to rolling, making the total tendency to roll about twice as great as without side slip. Also, for three monoplanes tested, the rates and ranges of autorotation were greatly increased by side slip, but for an unstaggered biplane they were only slightly affected.

*Maneuverability.*—The collection of quantitative data on the maneuverability of airplanes which it is expected will result in definite criteria for maneuverability and the factors which affect it has been continued. Reports on the maneuverability of two pursuit airplanes have now been completed. Also an investigation has been completed in which dives and

pull-outs of dives were performed on three different service fighter airplanes, each airplane being flown by three different pilots in the normal manner employed in diving bombing maneuvers. In each case continuous records were made of the accelerations, air speeds, and control movements, and such other data obtained as are necessary to establish the flight path of the airplane throughout the maneuver.

From the maneuverability data obtained on the pursuit airplanes mentioned above it has been possible to establish for pursuit airplanes an empirical relation between the altitude lost in recovering from a dive, the maximum acceleration encountered, and the air speed. This has been found useful in establishing the minimum safe altitude for starting the recovery from a dive without excessive loads on the airplane. Since the maneuverability measurements all include accelerations, they provide a valuable fund of information when analyzed from the structural loading standpoint.

*Structural design.*—The investigation of the probable external loads which come into play on aircraft structures in flight, as well as their distribution, still constitutes a major portion of the work of the flight research section. A report on the magnitude and distribution of the aerodynamic and inertia loads on a pursuit type airplane in a wide variety of maneuvers has been completed and is now in process of publication. Another investigation covering the distribution of aerodynamic loads over the fuselage of the same airplane has also been completed and the results are now being published. In this latter investigation it was found that aerodynamic loads on the fuselage are, in general, of such character that neglecting them altogether, as in current practice, results in conservative design.

A report on the water pressure distribution on a boat type seaplane has also been completed and published, completing an investigation of water pressures at landing on a series of single-float, twin-float, and boat type seaplanes.

An investigation of the pressure distribution on an airplane wing fitted with a systematic series of wing tips is now in progress, results having thus far been obtained on three tips of seven to be tested. The results obtained on the first tip have been published as a Technical Note. In this investigation it is hoped primarily to determine the effects of changes in tip plan form on the load distribution, so that arbitrary increases in the design stresses, as now required in the rules to allow for uncertain loads, may safely be removed. It is further hoped to establish the best form of wing tip consistent with structural requirements; that is, to determine the form which will produce the least severe stresses in the structure in the critical loading conditions.

The technique of measuring pressure distribution in flight has been greatly improved in the wing-tip investigation, so that for the first time results of such measurements are of sufficient accuracy to fully warrant conclusions as to the effect of small changes.

A study is being made of all of the available information on probable applied load factors with a view to formulating a more rational method for determining these loads for a given design than has heretofore existed. This study involves a number of flight investigations, which are now in progress, to gain further knowledge of the several elements which have a bearing on probable applied load factors. Of these, an investigation of terminal velocities under various conditions of engine operation has been completed. Calculated terminal velocities, with propeller drag properly taken into account, have been found to check the measured values with sufficient accuracy to justify their use in connection with one phase of the establishment of probable applied loads. The consideration given to the load-factor problem has led to the belief that the proper design load factors for transport and cargo-carrying airplanes may be dependent on the loads resulting from atmospheric disturbances. For the purpose of establishing these loads (and also the magnitude of the vertical currents causing them), the laboratory has developed a special recording accelerometer suitable for use in transport airplanes, and has made arrangements with operating companies whereby these accelerometers are carried in regular operation, the records, with other pertinent information, being returned to the laboratory for analysis. By this investigation it is believed that sufficient information will be obtained on the magnitude of the vertical currents actually encountered in transport operations to make possible the recommendation of new load factors for the design of transport airplanes. In this same connection, a study is in progress of all available meteorological information, in order to determine from another source the character of air currents which will cause appreciable loads to be imposed in flight.

Pressure distribution data obtained in the past are being further analyzed for the purpose of establishing design requirements for special parts of the airplane structure, such as the tail surfaces and the leading edges of the wings, as well as to establish better methods for determining the proper load and moment distribution to use in the design of the primary structure.

The pressure distribution tests on twisted wing models in the atmospheric wind tunnel have contributed information of value to the structural designer on the effect of twist and sweepback on the distribution of load along the span.

Since an airplane must be designed to withstand the shocks incurred in landing and taxiing, a saving

in structural weight is effected by incorporating suitable shock-reducing devices in the landing gear. For the purpose of determining the most suitable types of landing gears, investigations have been made of the shock-reducing and shock-absorbing qualities of several different types of oleo and rubber-cord landing gears, and also of low-pressure air wheels. The investigations consisted of dynamic (drop) and flight tests of each gear, the dynamic tests being made on an apparatus especially constructed for this work, while the flight tests were made with the gears installed upon the airplanes for which they were designed. The results of the investigation of the shock-absorbing ability of two gears, an oleo and a rubber-cord type, both designed for use on a pursuit airplane, have been published. A report on the tests of air wheels has also been prepared for publication. The air wheels were found to be comparatively ineffective as shock absorbers. Tests of gears for a training-type airplane are in progress.

The study of means of preventing the formation of ice on aircraft continues to be important from the standpoint of safety. The investigation of surface coatings in the refrigerated wind tunnel reported last year was followed by some tests on a model of the rubber "overshoe" developed by Dr. W. C. Geer in cooperation with the Guggenheim fund. The overshoe worked quite well in the tunnel, causing the ice to break off about as rapidly as it formed. The use of heat from the engine exhaust to elevate the temperature of the leading edges of the wings is now being investigated.

*Aerodynamic interference and drag.*—The study of aerodynamic interference during the past year has dealt principally with practical problems for which a solution might prove to be of immediate practical value. Among these problems are: The cowling of air-cooled engines; the interference between wings and fuselages and between wings and engine nacelles, including propeller interference effects; the interference between struts and wings; and the interference between the hull and the external parts of an airship. The investigation of such problems often provides much-needed and valuable information for immediate use, as in the case of the cowling of air-cooled engines. Furthermore, such investigations indicate the lines along which it will be most profitable to carry on more extensive investigations. Investigations of a more fundamental nature are also to be conducted. Combinations of simple objects will be tested, with a view to investigating separately the different ways in which it is possible for one body to interfere with the air flow over another.

During the past year the laboratory has continued its investigation of the low-drag cowling for air-cooled engines, and has made a study of a series of ring

cowlings, one of which was polygonal and arranged so that the angle of incidence of its surfaces could be varied. These cowlings were installed and tested on the Curtiss XF7C-1 airplane, using various combinations of fuselage shapes, in order to cover a wide range of conditions. During these tests information was obtained on the effects of cowling shape and angle, and fuselage shape on the high speed of the airplane, climb, landing speed, and engine temperatures. The information obtained has been prepared for two reports, which will be published during the coming year.

Little data are available concerning the interference effects arising from wing-brace struts as used on the familiar low-wing and high-wing single-engined cabin monoplane. In order to obtain data which would indicate in a general way the importance of such interference effects, tests were made in the variable-density tunnel on an airfoil with single and tandem sloping struts on both the upper and the lower surfaces. The results indicate large adverse interference when the struts are placed on the upper surface and the same effect to a less degree when they are placed on the lower surface. The adverse interference of tandem struts on the lower surface was found to be much less in proportion to the drag of the struts themselves than in the case of a single strut.

Another investigation of the same type in the variable-density tunnel consisted of testing combinations of a tapered wing and a fuselage of the type used on the Lockheed airplanes. High, medium, and low wing combinations were investigated, including also the effects of fillets between the fuselage and the wing in the low-wing position. The drag and interference of a landing gear on the high and low wing combinations were also determined. In regard to wing-fuselage interference, the high-wing combination was found the more efficient. The low-wing combination had increasingly more drag as the angle of attack and lift were increased. The use of fillets tended to improve this condition without, however, reducing the minimum drag.

An extensive investigation of the mutual effects of wings, nacelles, and propellers has been planned at the request of airplane manufacturers and is in progress in the propeller research tunnel. The first series of tests, using a thick wing and a cowled radial-engine nacelle with a tractor propeller, has just been completed. The wing has a chord of 5 feet. A 4-foot propeller is driven by an electric motor and the input power measured electrically. The nacelle interference and propulsive efficiency were determined for 21 positions of the nacelle with reference to the wing. A report is being prepared giving the results of this part of the program. Considering the effects on lift, drag, and propulsive efficiency, a nacelle located so that the

propeller is about 25 per cent of the chord directly ahead of the leading edge of the wing appears to be most satisfactory for cruising and high speeds and a position just above the leading edge is very poor. The complete program will include further tests with a thinner wing section, a series of nacelle positions with a pusher propeller, and another series with bi-plane wings. Tests are also contemplated with tandem propellers.

In 1927 an investigation of the drag due to the various parts of the Sperry Messenger airplane was carried out with interesting results. A similar series of tests has now been made of the drag of the engine, fuselage, landing gear, tail surfaces, and other parts of a Fairchild cabin monoplane. The results have been published as a Technical Note. The largest single item of drag was that of the radial air-cooled engine. The landing gear also showed a high drag. The drags of the tail surfaces, turtle back, and open cabin windows were small.

*Airships.*—There is an evident need for further information on the drag of airships, and in spite of the fact that wind-tunnel data are at best unsatisfactory because of the low Reynolds Numbers at which they must be obtained, it has been deemed advisable to include an airship investigation in the programs of the variable-density and propeller research tunnels as well as in that of the flight research section.

Tests in the variable-density wind tunnel on a model of the new Navy airship *ZRS-4* and on a model of smaller fineness ratio have been completed. The tests include the determination of lift, drag, and moment coefficients at various angles of pitch, both with and without control surfaces and cars. The results have been analyzed, and a report is being prepared which will include also the results of a previous series of airship-model tests in this tunnel.

At the request of the Navy Department it is planned to carry out in the propeller research tunnel a program of tests on a  $\frac{1}{10}$ -scale model of the new airship *ZRS-4*, and equipment is in preparation for this. In addition to measuring the drag under various conditions, it is planned to conduct a thorough investigation of the pressure distribution over the hull and fins and to measure the forces and moments on the fins.

The full-scale drag of an airship can be determined with reasonable accuracy in flight from the variation of the speed with time in deceleration runs in which the airship is propelled entirely by its own momentum. Deceleration tests have been conducted on the Navy metal-clad airship *ZMC-2* and a *TC* class and *TE* class airship during the past year. The information thus obtained on airship drag, together with previous data of this kind, has been collected and prepared in the form of a report on airship drag as affected by fineness ratio. An investigation has been made also



of the turning characteristics of the metal-clad airship.

*Airfoil studies.*—In order to extend the general knowledge of the aerodynamics of bodies, and particularly of airfoils, the effects of changing the dynamic scale or Reynolds Number have been investigated. This work is of value not only because it leads to the development of more efficient bodies but it makes possible the intelligent use and correct interpretation of some of the data from low-scale atmospheric tunnel tests. It is now possible to reach relatively high values of the Reynolds Number in airfoil testing at the laboratory in three different ways: In the variable-density tunnel, the propeller-research tunnel, and the high-speed tunnel, respectively.

A study has been made recently to compare the aerodynamic characteristics of several airfoils as obtained from tests in different atmospheric wind tunnels (including the variable-density wind tunnel at a pressure of one atmosphere) with those from the propeller research tunnel, and from the variable-density tunnel at higher Reynolds Numbers. The result of this study indicates that the discrepancy between the profile drag of airfoils as obtained from low-scale tests in different tunnels may be greater than the difference between the profile drags of two very different airfoils tested in the same tunnel. There is some discrepancy between the results of the large-scale tests, but it is relatively small, and the results are consistent in indicating systematic deviations from the low-scale results.

An investigation of the effect of scale on the distribution of pressure over airfoils has been completed and the results have been published. This investigation was carried out in the variable-density wind tunnel, and comprised the measurement of the pressures on several airfoils at both a low and a high dynamic scale or Reynolds Number. Concurrent with this investigation, a study was made of the character of the forces acting on an airfoil. This resulted in the development of an approximate method by which the force distribution along the chord of any normal airfoil may be predicted for all attitudes within the working range if the distribution at one attitude is known.

In connection with the subject of scale effect, it is worthy of note that excellent agreement was recently obtained between the maximum lift coefficient of an airfoil measured in the variable-density tunnel, and that of a complete airplane measured in flight. The flight measurements, which were carried to about 5° beyond maximum lift, were made on the Fairchild cabin monoplane, and the tunnel tests were made on the Göttingen 387 airfoil, which is the section used on the airplane.

An investigation of the effects of compressibility on the aerodynamic characteristics of airfoils is proposed

for the high-speed tunnel. A recording balance has been completed during the year and is ready for final calibration.

The results of a series of pressure-distribution tests made in this tunnel chiefly to check operation, using a moderately thick propeller section, show reduced normal force coefficients as the speed is increased beyond 0.6 sound velocity, and the pressure diagrams indicate a type of flow at high speeds which is somewhat similar to the flow at normal speeds but at high angles of attack.

The investigation of several very thick airfoil sections suitable for the inner portions of tapered airfoils and propeller blades has been extended. The part of the investigation mentioned in last year's report dealt with the effect of the scale of the test on discontinuities in the airfoil characteristics near maximum lift. The investigation has been extended by making tests to compare the characteristics of the airfoils at a large value of Reynolds Number and by conducting more extensive tests on a new metal model of one of the airfoils to investigate the effects of polish and higher air-stream turbulence and to extend the scale range to lower values of Reynolds Number. The tests have been completed and a report is being prepared.

The investigation of the effect of thickness and of the shape of the mean camber line on airfoil characteristics has been continued. Seven airfoils of a large family which were designed for this investigation have been constructed and tested. These airfoils, of various degrees of thickness and camber, were found to be as good as, and in some instances better than, some of the best of the commonly used sections. Other airfoils of the family are now being constructed. The investigation will be extended later by developing additional airfoils having a different distribution of thickness and different mean camber-line shapes.

Three tapered airfoils suitable for monoplane construction, based on the Clark Y and Göttingen 398 sections, have been tested in the variable-density tunnel and compared with the U.S.A. 45 tapered airfoil. Both airfoils show a higher maximum lift than the U.S.A. 45, the Göttingen 398 being highest, but they also have a slightly higher minimum drag. The aerodynamic characteristics of the tapered airfoils are almost as good as those of the rectangular airfoils from which they were derived.

In order that the results of all airfoil tests made in the variable-density tunnel and previously published in a number of separate reports may be made available for ready reference, they have been reduced to a standard form and published in a single report.

*Propellers.*—Investigations previously conducted in the propeller research tunnel have given valuable information on the various factors affecting propeller design. In order that this information may be readily



used by designers, a series of working charts has been prepared and published, making the solution of a practical problem in propeller design very simple.

A question of some importance to propeller designers is that of the effect of the airfoil shape. Tests have been conducted in the propeller research tunnel on three propellers having sections of the standard R.A.F. 6 modified and three having the Clark Y section. There were three thickness ratios for each section. The six propellers were tested at several pitch settings, and the results incorporated in a report now in process of publication. At low pitch settings the Clark Y section appeared the best, but this advantage disappeared at higher pitches. At the pitch settings normally used the R.A.F. 6 section shows an advantage in efficiency at the slip ratios corresponding to conditions of climb and take-off.

The question has been raised as to the effect of a locked or idling propeller on the landing speed of an airplane, particularly when the propeller is located in front of the wing. Tests recently completed indicate that the locked or idling propeller has a negligible effect on the lift, but that an uncowed radial air-cooled engine may have a very appreciable effect.

*Changes in equipment.*—In order that wind-tunnel experiments on autorotation and spinning may be more effectively carried out, there has been constructed during the past year a vertical wind tunnel having a 5-foot open throat. The autorotation dynamometer previously used in the horizontal atmospheric wind tunnel has been modified to permit vertical operation, and airfoil tests with this equipment are now in progress. Preliminary work on the design of a spinning balance for this tunnel has progressed to a stage where it seems fairly certain that a satisfactory piece of equipment can be built.

The old 5-foot horizontal tunnel has been replaced by a tunnel of the open-throat type, having a rectangular air stream 7 by 10 feet. This tunnel is now undergoing preliminary air-flow surveys and the balance is being installed.

The variable-density tunnel was operated for a time with an open throat, but difficulties arising from windage on the balance have led to the replacement of the open throat by a removable closed throat. Since it was not considered necessary when this tunnel was designed to operate at various air speeds, the tunnel was arranged to be driven by a synchronous motor. It has been found in recent months, however, that owing to varying loads on the lines of the local electric company from whom power is purchased, there have been variations in frequency which have produced very annoying fluctuations in air speed. It was decided, therefore, to replace the synchronous motor with a direct-

current motor with means for speed adjustment and a separate motor-generator set to furnish the current. This equipment is now being installed.

The construction of the full-scale tunnel, which has a throat 30 by 60 feet, is progressing in a satisfactory manner, and the indications are that the tunnel will be in operation within a few months.

#### BUREAU OF STANDARDS

*WIND-TUNNEL INVESTIGATIONS.*—The aerodynamic work at the Bureau of Standards has been for the most part along certain lines of fundamental research which are briefly described under the following sub-heads:

*Effect of turbulence in wind-tunnel measurements.*—The report on the effect of turbulence in wind-tunnel measurements was completed and published as Technical Report No. 342. This report shows the correlation between measurements of the forces on spheres and airship models and the magnitude of the average fluctuation in air speed as measured by the hot-wire anemometer. The results are interpreted in terms of the boundary layer theory.

*Transition from laminar to turbulent flow.*—The transition from laminar to turbulent flow has been studied in some detail for the case of a thin flat plate placed parallel to the wind. The measurements were made in the 3-foot wind tunnel, which is the tunnel having the least turbulence. The transition was found to occur at a Reynolds Number of the boundary layer of about 5,500, a value considerably higher than that found by Burgers and by Hansen. The high value is to be attributed to the low turbulence of the wind-tunnel air stream. Measurements of the fluctuations of air speed near the plate are in progress, and some interesting results have been obtained, but the work has not yet reached the stage of publication.

*Reduction of turbulence in wind tunnels.*—A study has been made of certain methods of reducing the turbulence in wind tunnels. The effects of modifications of a honeycomb in the front end of the working section and of adding a room honeycomb were found to be comparatively small. It appears that the most effective method of securing low turbulence is by the use of entrance cones with large area reduction with the honeycomb located in the low-speed section. A report on this work is being prepared.

*Characteristics of airfoils at high speeds.*—Measurements of the characteristics at high speeds of airfoils which are segments of cylinders have been completed. It has been found that sections of this shape are distinctly more efficient at speeds near and above the speed of sound than the R. A. F. or Clark Y sections. A moderate degree of rounding of the sharp edges does not materially change the characteristics and is in many instances beneficial.

*Rolling and yawing moments due to ailerons.*—The results of measurements of the rolling and yawing moments produced by ailerons of various chords and spans on 10 by 60 inch models of Clark Y and U. S. A. 27 wing sections at large angles of attack have been published as Technical Report No. 343. Measurements of hinge moments on these ailerons have been made in cooperation with the Aeronautics Branch of the Department of Commerce and the National Advisory Committee for Aeronautics.

*AERONAUTIC INSTRUMENT INVESTIGATIONS.*—The investigations on aeronautic instruments have all been carried on in cooperation with the Bureau of Aeronautics of the Navy Department and the National Advisory Committee for Aeronautics.

*Temperature coefficient of elastic moduli.*—Experimental work has continued on the determination of the temperature coefficient of the elastic moduli of diaphragm and spring materials for aircraft instruments in the temperature range from  $-50^{\circ}$  to  $+50^{\circ}$  C. A new method is being used in which the change with temperature in the deflection of a helical spring both in twist and in extension is observed. A second spring of the same material is coupled to the spring under test in order to balance the effect of elastic errors such as drift. Each spring is immersed in a liquid bath in order to control the temperature. A report which will be issued as Technical Report No. 358 has been prepared on the results which were previously obtained by means of a torsional pendulum.

*Friction of pivots.*—The dependence of the friction of steel step and shoulder-bearing pivots in brass bearings upon the finish and the wear of the pivots has been under investigation. Suitable apparatus has been perfected for this purpose. In the wear tests the friction was measured during the course of running the pivots with the axis vertical at a speed of about one revolution per minute. A report is in preparation. A report by A. Jaquero, L. Defossez, and H. Mägeli, entitled "Experimental Research on the Friction of Pivots," was translated and issued as Technical Memorandum No. 566.

*Report on speed measurement.*—A summary of the present status of the measurement of speed on aircraft has been practically completed. It includes two principal sections, one on the measurement of air speed and the other on the measurement of ground speed. The differential pressure, windmill, and hot-wire methods are considered in the first section, with emphasis on the differential pressure method and more particularly on the Pitot-static form. The theory of the Pitot-static instrument is given fully, including complete calibration tables and charts. Typical indicators and recorders are described. Their performance and problems connected with their installation in aircraft are discussed.

*Investigation of damping liquids.*—Most of the program of extending to  $-50^{\circ}$  C. the low-temperature limit of the viscosity data published in Technical Report No. 299 has been completed. Data were obtained during the year on the viscosity of about 36 pure liquids and solutions in the temperature range from  $-50^{\circ}$  to  $+30^{\circ}$  C., and also on the chemical stability and corrosiveness of a number of the liquids. The tests to determine the value of hydroquinone,  $\beta$ -naphthol, and diphenylamine in preventing the auto-oxidation of linseed oil and poppy-seed oil continue in progress. Further efforts were made, in close cooperation with the Bureau of Aeronautics and the manufacturer, to find a more suitable liquid for use in the ball-type inclinometer. These finally resulted in an increase in the clearance between the ball and tube and in the use of a solution of mineral spirits and a clock oil for the damping liquid. These liquids are readily obtainable, are noncorrosive, and soluble in each other in all proportions. A report is in preparation.

*Diaphragm investigation.*—Except for editorial work, the revision of the paper entitled, "The Evaluation of Elastic Afterworking for Instruments with Elastic Elements," has been completed. The methods of evaluating drift or creep, recovery, and elastic lag in aircraft instruments depending on the deflection of an elastic element, are given in detail, following Boltzmann's theory. General conclusions of value to the instrument engineer are included.

*Present status of air-navigation instruments.*—The report on this subject which was prepared at the request of the committee on problems of air navigation has been approved by the members of the subcommittee on instruments and has been submitted to the above committee.

*Instrument mechanism design.*—The report on the fundamentals of instrument mechanism design has been under revision during the past year.

*Vibration board.*—The construction of the nonmagnetic vibration board has been completed and is now in use for testing aircraft instruments. The Bureau of Aeronautics of the Navy and the Army Air Corps now specify a vibration test in which aircraft instruments are subjected to a circular harmonic vibration which has a double amplitude of one thirty-second inch in a plane  $45^{\circ}$  from the horizontal and frequencies ranging from 1,000 to 2,000 per minute. In view of this requirement a number of instrument manufacturers have constructed similar vibration boards.

*Electric resistance thermometer.*—An instrument of this type for measuring free-air temperatures was developed a number of years ago. Successive models have since been constructed, each embodying desirable refinements in the design. A new model was completed during the past year upon which it is planned to standardize.

*Suspended-head air speed meter.*—An instrument of the commutator-condenser type has been constructed for use on the airship *Los Angeles* which is a distinct advance over older models. An automatic voltage regulator has been provided which operates in the range from 11 to 14 volts with an accuracy of better than 0.5 per cent. A modified electric circuit and a galvanometer of greater sensitivity are used, which permit reduction of the electrical capacity from 7 to 1 microfarads. The reel has been provided with a brake, as well as the usual positive stop.

#### WASHINGTON NAVY YARD

The wind-tunnel equipment at the Washington Navy Yard consists of an 8 by 8 foot closed-circuit type, which is continuously employed on current design work for the Bureau of Aeronautics. During the past year the old 4 by 4 foot N. P. L. type wind tunnel has been dismantled for replacement by a larger tunnel capable of testing airplane models. The new tunnel now under construction is to be of the closed-circuit type with a circular test section of about 6-foot diameter. When completed it will be used, like the 8-foot tunnel, on current design problems, although, as in the past, a limited amount of general research investigation will be done.

*Airplane models.*—During the past year 23 model airplanes were given complete tests in pitch and yaw. Many of these models were given additional tests to determine the effects of various modifications, such as changes in tail surfaces, fairings, wing arrangement, etc. The completion of the new wind tunnel will enable the extension of this work to cover thorough investigation of current designs.

*Airfoils.*—Routine tests have been made on 12 airfoil sections during the year. Eleven of these sections belong to the Navy series and the other was submitted by a commercial airplane company. One of the new Navy sections appears to have such unusually desirable characteristics that additional tests are being made on a slight modification.

*Control surfaces.*—With one exception the tests on control surfaces have been a part of the routine airplane-model tests noted above. In this case an unusual type of aileron was tested for rolling and yawing moments, which were not sufficiently improved to justify its use.

*Radiators.*—Two full-scale sections of wing radiators were tested for drag and cooling properties under various conditions of flow rate, flow direction, and cooling fluids. Another model, completing this series, is to be tested in the future.

The tests on airship power cars with Venturi-cowled radiators have been completed. It appears that the use of a good cowling will reduce the radiator drag more than 50 per cent.

#### MATÉRIEL DIVISION, ARMY AIR CORPS

*Wind tunnels.*—The wind-tunnel equipment at Wright Field consists of two wind tunnels, a 5-foot tunnel and a high-speed tunnel 14 inches in diameter, both of the N. P. L. type. Most of the investigations at Wright Field are conducted in the 5-foot wind tunnel, which was moved from McCook Field.

*Routine tests.*—Routine wind-tunnel tests have been made of models of the *XHB-3*, *XA-7*, *XO-31*, and *XP-9* airplanes.

*Wheel drag.*—Tests were made on full-sized wheels and tires to obtain a comparison between the drag of a Musselman wheel 22 by 10 inches and a conventional wheel and tire 30 by 5 inches. Wooden models of various streamline wheels were also tested.

*Slotted wing.*—Tests were made on a model of a Clark Y wing fitted with an automatic leading-edge slot to determine the angle of attack at which opening occurs. An experimental multiple-slot model wing was also tested.

*Fuselage shapes.*—A series of drag tests was made on a model of the *P-1* airplane. Variations were made in the fuselage fairings and location of the radiator. Tests were also run on the model with open cockpit and with enclosed cockpit.

*Tail surfaces.*—The investigation of the characteristics of the horizontal tail surfaces of a  $\frac{1}{8}$ -scale model of the *AT-5* fuselage was continued, a larger stabilizer being used with and without balanced elevator.

*Airplane skis.*—Drag tests were run on full-sized skis for pursuit airplanes to determine the best aerodynamic shape.

*Revolving loop antenna.*—A revolving loop antenna was given a mechanical test in the tunnel to determine its drag and rotational properties.

*Landing lights.*—Airplane landing light models were installed at various locations on a model airplane and tests made to determine the position for minimum drag.

*Infinite span wing.*—The characteristics of a Göttingen 436 model wing which was arranged to simulate infinite span conditions were determined.

*Ring cowl.*—Ring cowls of various shapes were tested for drag on a model of the *XO-14*.

*Motorized observation balloon.*—The lift, drag, pitching moments, and yawing moments of a motorized observation balloon model were measured.

*Drag of external bombs.*—Model bombs were installed in various arrangements and with varying amounts of clearance between bombs and between bombs and fuselage, on a model of the *XA-7* airplane and tested for drag.

*Performance calculation methods.*—Several methods for computing airplane performance and for determining the basic data required for use with the per-

formance methods were investigated and checked against flight test data. A greater amount of comparative data will be necessary in order to arrive at a decision on the best method.

*Shock absorbers.*—Characteristics of oil flow through orifices under high pressures as encountered in oleo shock-absorber designs were investigated. A special 6-foot stroke oleo leg was used in this investigation in connection with the recently developed time-deflection recorder.

This apparatus was also used in routine impact tests on different makes of shock absorbers and tires, whereby the instantaneous accelerations of the masses and the efficiency of the shock absorbers were accurately determined.

A new maximum-load recording accelerometer was also developed which is used in the laboratory and also on airplanes during flight and landing.

## REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

### ORGANIZATION

The committee on power plants for aircraft is at present composed of the following members:

- Dr. S. W. Stratton, Massachusetts Institute of Technology, chairman.
- George W. Lewis, National Advisory Committee for Aeronautics, vice chairman.
- Henry M. Crane, Society of Automotive Engineers.
- Prof. Harvey N. Davis, Stevens Institute of Technology.
- Dr. H. C. Dickinson, Bureau of Standards.
- Carlton Kemper, National Advisory Committee for Aeronautics.
- Capt. E. R. Page, United States Army, matériel division, Air Corps, Wright Field.
- Commander C. A. Pownall, United States Navy.
- Prof. C. Fayette Taylor, Massachusetts Institute of Technology.

### FUNCTIONS

The functions of the committee on power plants for aircraft are as follows:

1. To determine which problems in the field of aeronautic power-plant research are the most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding aeronautic power-plant research in progress or proposed.
4. To direct and conduct research on aeronautic power-plant problems in such laboratories as may be placed either in whole or in part under its direction.

5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

By reason of the representation of the Army, the Navy, the Bureau of Standards, and the industry upon this subcommittee, it is possible to maintain close contact with the research work being carried on in this country and to exert an influence toward the expenditure of energy on those problems whose solution appears to be of the greatest importance, as well as to avoid waste of effort due to unnecessary duplication of research.

The committee on power plants for aircraft has direct control of the power-plant research conducted at Langley Field and also of special investigations authorized by the committee and conducted at the Bureau of Standards. Other power-plant investigations undertaken by the Army Air Corps or the Bureau of Aeronautics are reported upon at the meetings of the committee on power plants for aircraft.

### LANGLEY MEMORIAL AERONAUTICAL LABORATORY

*COMPRESSION-IGNITION ENGINES.*—One of the greatest detriments to the use of aircraft by the public as a means of transportation is the present liability of aircraft to burn if crashed during a forced landing. Although the latest aircraft are built largely of metals which are fire resistant, the gasoline used as fuel and the high operating temperatures of some parts of carburetor engines are factors which contribute directly to the fire hazard. It is for this reason that the committee has continued the research to develop power plants for aircraft which will reduce the fire hazard by using fuels of low volatility. The factors which militate against the use of engines operating on low-volatile fuels are their lower power output per cubic inch of displacement and higher maximum cylinder pressure compared with present gasoline engines. The various investigations undertaken by the committee on the compression-ignition engine are directed, therefore, toward increasing the specific power output of this type engine and still maintaining low maximum cylinder pressures.

*Analysis of cycle efficiencies.*—Since the effect of such variables as maximum cylinder pressure, compression pressure, and compression ratio on the cycle efficiencies of compression-ignition engines can not be readily determined from engine tests because of the large number of variables which must be controlled, it has been necessary to develop methods for calculating the theoretical effect of these factors. A general method of calculating the cycle efficiencies of compression-ignition engines operating on the dual combustion cycle is being developed. The calculations are to be based on the complete combustion of 1 pound of fuel, which will vary the composition of the working fluid

at different points in the cycle. The thermal capacity of the mixture is to be regarded as a function of temperature and composition. A report on this general method of calculating cycle efficiencies is being prepared for publication.

A graphical method of determining the cycle efficiencies based on the general method is also being developed. These graphs will make it possible to determine readily all factors of the cycle if the suction pressure and temperature, compression ratio, maximum cylinder pressure, and quantity of excess air present are given. The graphs will be applicable to the Otto and Diesel cycle as well as to the dual combustion cycle. A report on this method of calculating cycle efficiencies is being prepared for publication.

*Combustion chamber investigation—Integral type.*—The investigation of the effect on engine performance of the distribution of the fuel by means of multi-orifice nozzles throughout a combustion chamber with little or no effective air flow has led to the adoption of the principle of proportioning the areas of the individual orifices to the volume of air served by the fuel spray from each orifice. This resulted from observation with nozzles having orifices in only one plane. To determine the extent to which this principle should be followed, a nozzle has been tested which was designed to have 16 orifices in three planes. This nozzle was constructed by drilling two orifices at a time, and engine performance tests were made after each pair of orifices was added. These tests indicate that there is no advantage to be gained by following the proportion principle to such an extent as to make the construction of the nozzle too complicated.

With the object of increasing the degree of air movement in this combustion chamber a special throat was installed to direct the air flow in such a manner that an air swirl would be induced in the combustion chamber. The tests under these conditions showed that the cost of producing the air flow was a 35 per cent increase in the friction horsepower and an 8 per cent decrease in volumetric efficiency. The increase in combustion efficiency obtained did not offset this penalty. These tests have shown that this type of cylinder head is not suitable for use with a high degree of air flow nor for the intelligent study of the effect of air flow on combustion as evidenced by engine-performance data.

This engine has also been used for an investigation of dual-rate injection. An analysis of the theoretical dual combustion cycle indicates that the fuel charge should be injected slowly at first and rapidly after combustion has been started. With a set of orifices of constant area controlled by a single stem, the obtaining of a wide variation in injection rates is impossible. For this reason an injection valve was designed and tested having two concentric stems each controlling a

separate set of orifices. Since there was a difference in opening pressure of the valve stem, it was possible to have one set of orifices start injection at a lower pressure than the other. By the use of different rates of plunger displacement it was possible to make the primary injection lead the main injection from  $3^\circ$  to  $90^\circ$  of crank angle as observed with the oscilloscope.

The nozzles used were each similar to a single-rate nozzle for purposes of comparison. One type of nozzle placed the primary sprays in the relatively cool outer part of the combustion chamber to determine the effect of heating a part of the fuel charge before the main injection took place. The other type placed the primary sprays across the valve heads to create a superheated area into which the main jets were discharged. Neither type of nozzle gave any better performance than the corresponding single-rate nozzle, and the performance of the engine became better as the lead of the primary sprays was reduced; that is, as they approached the single-rate condition. Thus, in this work to date, there has been found no evidence of any advantage in dual-rate injection.

*Combustion-chamber investigation—Precombustion-chamber type.*—The investigation of the velocities and direction of air flow in the precombustion chamber led to the design and testing of a precombustion chamber of a spherical shape instead of the pear shape formerly used. The higher air velocities, due to less interference with the air flow, gave higher rates of pressure rise, higher maximum cylinder pressures, and greater sensitiveness to injection timing. The experimental work with the present engine has shown that, with high velocities of air flow, the degree of atomization of the fuel as it enters the precombustion chamber has little effect on engine performance and that the timing of the injection must be maintained within a very limited range for best operation. These tests also indicated that with the present engine it would be difficult to investigate the variables controlling the type of combustion obtained with the precombustion chamber. A new single-cylinder test engine has been obtained with which to continue the work on cylinder heads having precombustion chambers. This new engine will make it possible to continue this investigation with more speed, and to test a greater number of precombustion-chamber designs.

*Fuel-injection systems.*—The investigation of the pressure variations in a common-rail fuel-injection system in which the source of pressure is at some distance from an automatic injection valve has been completed and the results presented in the form of a Technical Report. The instantaneous pressures at the discharge orifice were determined by analyzing the stem-lift records of the injection valve. It was found that in such an injection system pressure waves did occur, but that these pressure waves could be controlled in a

manner advantageous to the injection of the fuel. The instantaneous pressures at the discharge orifice were found to be independent of the speed at which the injection system was used. In addition it was found that the length of the injection tube in inches in such a system should be twice the maximum injection period in ten-thousandths of a second in order to obtain a constant pressure of injection.

The investigation of the time lag between the release of pressure in the injection system of the N. A. C. A. spray photography equipment and the appearance of the jet from the discharge orifice has been completed. The results have been presented in the form of a Technical Note. It was found that the time lag varied directly with the length of injection tube, increased with an increase in injection valve opening pressure, decreased with an increase in injection pressure, and remained independent of initial pressure in the injection tube, providing the injection pressure was considerably in excess of the initial pressure.

Following the investigation of the common-rail fuel-injection system an investigation of a pump fuel-injection system was started. The same method was used for determining the instantaneous pressures at the discharge orifice of the fuel-injection valve. The experimental work has been completed. It was found that variations from  $4\frac{1}{2}$  to 34 inches in the length of injection tube had little effect on the injection characteristics. Injection-valve closing pressures had considerable effect on the characteristics. Increasing the closing pressure increased the instantaneous pressures, but decreased the injection period. When the injection-tube diameter was increased it was found that there was a tube diameter which gave the maximum injection pressures and that this tube diameter was of a size comparable to the dimensions of the fuel pump. The throttle setting had no effect on the instantaneous pressures up to the time when cut-off occurred. The use of a check valve between the pump and the injection tube was found to be extremely important, since without it the injection was difficult to control.

A theoretical analysis has been made of the instantaneous pressures delivered by a fuel pump and the analysis checked against the experimental data. Using Sass' adaptation of the Allievi theory of water-hammer, it was found that the theoretical pressures checked the experimental pressures reasonably well. A theoretical investigation was also made of the effect of injection-tube diameter, and the results of this investigation are being prepared for presentation as a Technical Report.

The investigation of the effect of the ratio of orifice length to diameter on spray characteristics has been continued. The 0.014 and 0.040 inch orifices have been

investigated for ratios from 0.5 to 4. It was found that the variation of rate of spray penetration was materially affected by the ratio of orifice length to diameter. As the ratio was increased from 0.5 the penetration at the end of 0.001 second first decreased, reaching a minimum, and then increased. The experimental data indicated that maximum penetration with the 0.040-inch orifice was reached at a ratio of 4, while with the 0.014-inch orifice the penetration was still increasing at this ratio. The results obtained indicate that the same effects are obtained whether straight or helically grooved stems are used, although the effects are less marked with the helically grooved stems. This information is being prepared for presentation as a technical note. The investigation is being continued to include orifice diameters of 0.008, 0.020, and 0.080 inch for ratios of length to diameter from 0.5 to 10. Injection pressures from 2,000 to 6,000 pounds per square inch and chamber pressures from 60 to 250 pounds per square inch are being used in the investigation.

In conjunction with the investigation of the effect of orifice length-diameter ratio on spray characteristics the effect of this ratio on the coefficient of discharge has also been investigated. It has been found that the coefficient is not affected for ratios from 0.5 to 4. The investigation included the effect of the entering edge of the orifice on the coefficient. It was found that with sharp entering edges the coefficient could not be controlled, but varied for different orifice diameters and different back pressures into which the liquid was discharged. When the entering edge of the orifice was beveled to  $60^\circ$  and all the corners slightly rounded, the coefficient remained practically constant at 0.94 for Reynolds Numbers over 2,000, regardless of the orifice diameter or the back pressure into which the fuel was discharged. This information has been prepared for presentation as a Technical Report. The investigation of the coefficient of discharge is being continued for ratios of 0.5 to 10. The discharge pressures are being varied from 500 to 6,000 pounds per square inch and the back pressure into which the discharge takes place from atmospheric pressure to 1,000 pounds per square inch.

*Engine indicators.*—The laboratory has continued to use a modified Farnboro indicator for composite pressure-time cards of test-engine cycles. Some additional changes have been made in the recording mechanism which allow each card to be calibrated accurately as to both time and pressure as the card is being generated by the engine.

The balanced-pressure, diaphragm-type maximum cylinder pressure indicator has been redesigned as a more compact unit which will be easier to service and less likely to leak or to burn out the inner support



in case of a diaphragm failure. Two of the redesigned units are now in service on the test engines at the laboratory.

**INCREASE IN ENGINE POWER—Two-stroke cycle investigation.**—To investigate the possibilities and limitations of increasing the specific power output of aircraft engines by using the 2-stroke cycle and fuel injection with an air-cooled cylinder, a single-cylinder test unit of this type has been designed and constructed and is now undergoing preliminary power tests.

This engine uses an N. A. C. A. Universal test engine base with a Liberty air-cooled cylinder. Both valves in the cylinder head are used as exhaust valves and the air enters through ports in the cylinder wall. About these ports is a manifold with directing vanes, which by adjustment causes the air to flow into the cylinder either radially or tangentially. Air for charging and scavenging is furnished by a separately driven Roots-type supercharger. Air for cooling the cylinder is supplied by a propeller-type blower. The cylinder is equipped with thermocouples, and a continuous record of temperatures is made by a multiple-recording pyrometer.

The fuel may be injected into the cylinder just above the intake ports or it may be injected directly into the combustion chamber. Diametrically opposed holes are provided so that injection is directed against the spark plug in the combustion chamber or fuel may be injected from both sides of the cylinder simultaneously. The fuel-injection pump is of the port-control type especially designed for high-speed operation. The fuel-injection valve used at present is automatic, with a spring-loaded stem and a nozzle having opposed orifices which give a spray that is very finely atomized and is almost flat and circular in shape. The fuel-injection system may be used with either gasoline or Diesel oil.

**Investigation of supercharging at various compression ratios.**—There are two methods of increasing the power output of present carburetor engines which are being investigated. The first is by increasing the compression ratio and the second is by supercharging at a low compression ratio. Increasing the compression ratio has the advantage of giving higher thermal efficiency. The amount the compression ratio can be increased for commercial engines, however, is limited by the difficulty of obtaining a sufficient quantity of nondetonating fuels. Increasing the compression ratio is further limited by a rapid increase in maximum cylinder pressure. This increase in pressures requires that the weight of the engine cylinders and reciprocating parts must be increased or the reliability of the engine will be decreased. Supercharging at low compression ratios has the advantage that a high power output can be obtained with a low maximum cylinder

pressure. With this method both the power output and the reliability of the engine can be increased without additional weight.

The engine tests for this research were conducted on an N. A. C. A. Universal test engine using a Roots supercharger to boost the pressure at the carburetor. A range of compression ratios from 3.5 to 7.5 and carburetor pressures from atmospheric to approximately 12 inches of mercury above atmospheric were used. Benzol was used as a fuel so that the tests would not be complicated by detonation. The maximum cylinder pressures were indicated by a balanced-pressure diaphragm-type indicator similar to that developed by the Bureau of Standards. Indicator cards were taken with the Farnboro electric indicator.

At a compression ratio of 6.5 and with the maximum cylinder pressure limited to 900 pounds per square inch it was possible to obtain a brake mean effective pressure of 195 pounds per square inch at 1,500 r. p. m. with a carburetor pressure of 40 inches of mercury. The specific fuel consumption was 0.50 pound per brake horsepower per hour. Supercharging to 42 inches of mercury at a compression ratio of 4.5 gave a brake mean effective pressure of 181 pounds per square inch and a maximum cylinder pressure of only 600 pounds per square inch. The corresponding fuel consumption was 0.59 pound per brake horsepower per hour. A report of this investigation is being prepared for publication.

**Investigation of valve timing.**—The laboratory test work in connection with the valve timing of supercharged and unsupercharged engines has been completed. The best valve timing was determined for a single-cylinder test engine having a 5-inch bore and a 7-inch stroke when operated unsupercharged at sea level and under conditions of inlet and exhaust pressures corresponding to those of a supercharged engine at altitudes from 0 to 18,000 feet. In the first part of the investigation the timing of the inlet and exhaust valves was varied independently and performance measurements taken for each setting. This was followed by measurements of performance for the best valve timing, obtained by varying each factor until there was no further increase in power. The tests were conducted at speeds of 1,200 and 1,500 r. p. m. The effect of compression ratio was determined by operating with different valve timings at compression ratios of 4.35, 5.35, 6.35, and 7.35. A Technical Report presenting the results of this investigation has been prepared for publication.

**Cooling efficiencies of finned cylinders.**—The development of an aircraft engine capable of delivering 1,000 horsepower is one of the present needs of both the military services and the air transport companies. Although the radial air-cooled engine has been developed to give over 600 horsepower, it is generally

believed that for the larger power output the air-cooled cylinders will not be capable of efficient cooling and it will be necessary to use liquid cooling. However, the present design data relative to the efficiencies of various types of fins for the cooling of engine cylinders are meager. An investigation has therefore been undertaken to determine the maximum quantity of heat which can be efficiently dissipated from finned metal cylinders to an air stream.

The efficiency of a given design of fin will be determined by measuring the electrical energy dissipated as heat to the cooling air. A satisfactory electrical heating unit and separately heated guard rings have been developed for each finned test specimen. A Venturi-type wind tunnel having a 30-inch throat and a maximum velocity of 160 miles per hour has also been constructed for this research. Work will shortly be started on the testing of the finned cylinders.

**SUPERCHARGER INVESTIGATIONS—Comparative performance of superchargers.**—The analysis of available data to determine the comparative performance of superchargers has been completed. The superchargers were compared on the basis of power required to compress at a definite rate and on the basis of net engine power developed at altitude depending on the type of supercharger used. The performances of geared centrifugal, turbocentrifugal, Roots, and vane type superchargers were investigated for altitudes from 0 to 40,000 feet. The results of this investigation show that for altitudes up to 20,000 feet, when suitable methods of control are employed, there is very little difference in superchargers from the point of view of net engine power. For altitudes over 20,000 feet, however, an engine develops more power when equipped with a turbocentrifugal supercharger than with any other type. The Roots supercharger, owing to its inefficient type of compression at high altitudes, gives the lowest engine power. The control used on a geared centrifugal supercharger is very unsatisfactory from the point of view of power when compared with that of the Roots or turbocentrifugal supercharger.

**The turbocentrifugal supercharger.**—A report has been prepared and published comparing the performance data obtained with a modified *DH-4M2* airplane powered with a Liberty engine. This airplane was first equipped with a Roots type supercharger and later with a turbocentrifugal supercharger. It was found that the rate of climb and ceiling were practically the same with the two superchargers, but that as the altitude of operation was increased the turbocentrifugal gave the higher speed. The difference in speed between the two types of superchargers increased gradually, reaching 20 miles an hour at an altitude of 21,000 feet.

**Clearance tests of Roots supercharger.**—Flight and laboratory tests of the N. A. C. A. Roots type super-

charger have shown that the clearances between the impellers and the case greatly influence the discharge air temperatures and the performance characteristics of this type of supercharger. Tests are now in progress to determine the magnitude of this effect. In these tests the discharge and intake air temperatures, power requirements, slip speed, and the change in clearance with speed and pressure difference will be determined for the useful range of speeds and pressure differences, with five different tip and end clearances ranging from the minimum practical to approximately 0.025 inch. The supercharger has been mounted on a test stand and an air-measuring system installed. Thermocouples have been provided to obtain temperature measurements at 12 points on the case. Electrical indicators have also been made and installed for measuring the clearances.

Tests are now in progress to determine the performance characteristics of a Roots type De Palma supercharger. The supercharger has been tested at speeds of 500, 1,000, 1,500, 2,000, and 2,500, with pressure differences of 3, 6, 9, 12, and 15 inches of mercury. The tests will be continued at higher speeds. These tests will be of interest in that the clearances are much less than have yet been tried for this type of supercharger. Steel impellers are used in an aluminum case instead of the magnesium alloy impellers used in the N. A. C. A. Roots type. A Technical Note will be prepared showing the comparative performance of the N. A. C. A. and De Palma superchargers.

#### BUREAU OF STANDARDS

**Supercharging of aircraft engines.**—Altitude-chamber performance tests of a Curtiss D-12 engine equipped with a Roots type supercharger having a rated altitude of 5,000 feet at 2,000 r. p. m., were made for the Army Air Corps. Power and friction runs were made at four engine speeds and under conditions corresponding to altitudes from sea level to 25,000 feet. Tests of the same engine equipped with a geared centrifugal supercharger having a critical altitude of 15,000 feet at 2,300 r. p. m. are now in progress.

Sea-level tests of the Curtiss D-12 engine at carburetor air temperatures ranging from 15° C. to 100° C. gave results in fair agreement with the usual correction formula which assumes that indicated horsepower varies inversely as the square root of the absolute temperature (see Technical Report No. 190 of the National Advisory Committee). However, the increase in indicated horsepower when the carburetor air was cooled from +15° C. to -20° C. was somewhat less than would be predicted from the above relation. Tests were also made with the pressure in the altitude chamber reduced to correspond with various altitudes but with sea-level pressure maintained at the carburetor intake and in the exhaust manifold. With the cham-



ber at maximum altitude the engine developed about 2 per cent less than normal sea-level power, indicating that approximate altitude tests under supercharging conditions tend to give abnormally high results.

*Phenomena of combustion.*—Some 3,500 photographic records of the progress of the gaseous explosive reaction as it occurs at constant pressure in a soap bubble used as a bomb have been analyzed to determine the effect of pressure on the rate of reaction. The experimental data, covering a variety of pure and composite gaseous fuels and a range of constant pressures from 100 mm. to 2,650 mm. of mercury, show that for a charge of given proportions the linear rate of propagation of the reaction zone within the explosive gases is constant and independent of pressure, and that as a result the rate of molecular transformation is proportional to pressure. A report presenting these results and discussing the characteristics of the explosive reaction as they apply to its technical and industrial applications as a source of power, will soon be published by the National Advisory Committee for Aeronautics under the title, "The Gaseous Explosive Reaction—The Effect of Pressure on the Rate of Propagation of the Reaction Zone and Upon the Rate of Molecular Transformation."

Papers on related subjects by R. Duchêne and R. Wendlandt have been translated and issued as Technical Memorandums Nos. 547, 548, 553, and 554.

*Combustion in an engine cylinder.*—Stroboscopic observations of the movement of the flame and simultaneous measurements of the development of pressure in the combustion chamber of a single-cylinder test engine have been made over a wide range of operating conditions and with a variety of pure hydrocarbon gases as fuels. The results of these tests are being analyzed and a detailed report covering the work on gaseous fuels is in preparation. Meanwhile, the engine is being equipped to burn liquid fuels and tests will be resumed under conditions permitting normal burning and also under conditions leading up to and causing detonation. A number of special cylinder heads have been constructed for use in studying the effect of combustion-chamber shape and number and location of spark plugs on flame travel and pressure development.

*Temperatures and pressures in an aircraft engine.*—Pressure measurements made with a balanced-diaphragm indicator on a single-cylinder variable-compression Liberty test engine have not appeared sufficiently reliable to warrant the making of a large number of indicator diagrams for careful analysis. Instead, efforts have been directed toward the attainment of more precise and significant diagrams. A study of "motoring" cycles, during which pressures repeat very consistently from cycle to cycle, is being made as a check on possible errors in the indicator

and in an effort to account for certain illogical-appearing exponents of compression and expansion which have been obtained. A search for the cause of the wide variation in explosion pressures from cycle to cycle found in all engines and for possible methods of eliminating this variation is also in progress.

*Effect of spark character on ignition ability.*—In continuing the study of spark ignition, requested by the National Advisory Committee for Aeronautics and the Navy Department, the relative effectiveness of ignition sparks was compared by determining the amount of chemical reaction which takes place when different sparks are passed through an explosive mixture of oxygen and hydrogen at low pressure and liquid-air temperature. Spark character was altered by varying the electrical constants of the ignition circuit. The results are presented in Technical Report No. 359, entitled "An Investigation of the Effectiveness of Ignition Sparks." The amount of reaction occurring when magneto sparks are passed through very lean mixtures of oxygen and hydrogen at atmospheric pressure is now being studied. In this case, at least, it is found that gap length has more effect on the amount of reaction per spark than considerable changes in resistance, inductance, or capacitance. To measure spark character more precisely a cathode-ray oscillograph will be required.

Apparatus has been installed for testing the reliability of shielded ignition harnesses for aircraft engines when subjected to water spray, in accordance with the proposed requirements of the Department of Commerce. A few shielded harnesses have been submitted to this test, but further development work is required before the routine testing of ignition shielding equipment can be undertaken.

*Gaseous fuels for airship engines.*—Tests of pure gaseous fuels in a single-cylinder variable-compression Liberty test engine were financed by an industrial concern through the National Research Council. Runs were made at full throttle and 1,000 r. p. m. to determine relative power, economy, and antiknock value; also mixture-ratio and spark-advance requirements for the following fuels: Methane, ethane, propane, ethylene, and propylene. For gases of the paraffin series the tendency to detonate decreases as the weight of the molecule decreases, no detonation being obtainable with methane even with an excessive spark advance at the highest compression ratio available (13:1). Gases of the olefin series are inferior to those of the paraffin series, but all of the gases tested are far superior to gasoline in antiknock value. The relative power obtainable from the several gases is, roughly, equal to the relative heating values for unit volumes of "correct" mixtures of air and fuel. Maximum-power mixture-ratio and spark-advance requirements differ more for gaseous than for liquid fuels.

*Effect of air humidity on engine performance.*—Further engine tests, covering a range of humidity from 1 to 80 mm. of mercury pressure of water vapor, support the hypothesis that moisture in the air acts merely as an inert diluent in reducing engine power if detonation is absent. The effect of humidity on detonation was also studied and water vapor was shown to exert an antiknock effect in addition to its diluent action. Some methods of knock rating appeared to be affected more than others by changes in humidity.

In connection with this work, which was requested by the Navy Department, it became necessary to include a study of methods of measuring humidity and a modified psychrometer has been developed which shows much higher precision than the standard types of psychrometer.

*Vapor lock in airplane fuel systems.*—Laboratory work on the vapor pressures of numerous representative aviation gasolines led to a general relation between distillation data and vapor pressures which made possible a prediction of the conditions under which vapor lock would occur. To test this relation flow experiments were made with a variety of gasolines in typical airplane fuel-feed systems over a considerable temperature and pressure (altitude) range in each case. The observed conditions for vapor lock were in good agreement with the conditions predicted from the general vapor-pressure relation. In gravity feed systems the flow was found to be affected by such design factors as bends, constrictions, and changes in cross-sectional area. With a gear fuel pump the flow was affected by height of suction lift, minimum lift being desirable. In the case of airplane carburetors the size of vent on the float bowl was found to be important. If the vent is too small, pressure will be built up in the float bowl when vapor lock occurs, with resultant engine stoppage due to overrichness. There is probably an optimum size of vent for each type of carburetor to prevent excessive leaning or enrichment of the mixture under vapor-locking conditions. From data thus far obtained, in cooperation with the Army and the Navy, on fuel-line temperatures in airplanes during flight, it appears increasingly evident that the temperature of the gasoline in the tank as the airplane leaves the ground is the major controlling factor in vapor lock.

*Type testing of commercial aircraft engines.*—Three torque-stand testing units have been in service at the Arlington engine-testing laboratory most of the year and a fourth unit is being provided. By operating all units on a 2-shift basis during the past two months the testing of engines has been brought practically up to date. Of 52 engines received for test during the year, 26 passed, 23 failed, and 3 were withdrawn. The engines which failed included 10 new types and 4 which had each received at least one previous test.

Seven engine types failed two or three times each during the year, whereas several others passed on re-test after an initial failure. The most common sources of major failure were as follows: Crank shaft (4), crank case (4), cylinder (3), piston seizure (3), and exhaust valve (3). At the end of June 54 engines had received approved-type certificates from the Department of Commerce.

#### NEW ENGINE TYPES

The development of aircraft engines has kept pace with research work during the past year. Every effort has been made to increase the power output of the present liquid-cooled and air-cooled engines. Refinement of design, increased revolutions per minute, increased compression ratio, and the use of supercharging have led to a material increase in the horsepower developed. The normal brake mean effective pressure of engines now in operation is about 130 pounds per square inch, and from experimental tests indications point to the fact that this figure may be raised to 160 pounds per square inch.

Considerable interest has been shown by the industry in fuel-injection systems, and marked progress has been made in several experimental projects. The results obtained so far are very promising and tend toward the belief that the eventual elimination of the carburetor is definitely possible.

There is an increasing demand for an aircraft engine of higher power than is now available, not only for the military services but for commercial aviation as well. This need has become pronounced with the increasing demand for larger passenger-carrying airplanes which require from 2,000 to 3,000 horsepower. With the present engines an aircraft of this large size necessitates a design which is not particularly efficient structurally nor aerodynamically. Accordingly several engine manufacturers are investigating the possibilities of engines having an output between 1,000 and 2,000 horsepower, and have actual experimental projects under way.

The low-drag cowling has been used considerably in commercial aircraft, especially in the high-speed class. Its effectiveness in reducing the resistance of the radial engine is attested by the fact that all the high-speed records in this country for the past year have been made with airplanes having radial engines fitted with this type of cowling.

The Bureau of Aeronautics of the Navy Department and the matériel division of the Army Air Corps have continued the development of the accepted standard types of engines used by the services.

Development work has been continued on the Curtiss V-1570 and D-12 engines, with a view to obtaining satisfactory operation and performance, using higher

compression ratios, supercharging, and Prestone cooling.

The Curtiss V-1570 is a 12-cylinder V-type water-cooled engine with geared drive, and is rated by the Department of Commerce at 600 horsepower at 2,400 r. p. m. This engine has been fitted with a heavier crank shaft and has been refined to permit the attainment of higher speeds.

The Pratt & Whitney Aircraft Co. has continued development work on the Wasp 9-cylinder radial engine. This engine is rated at 420 horsepower at 2,000 r. p. m. and is standard equipment for a number of types of service airplanes and is extensively used in commercial service.

The Hornet engine, manufactured by the same company, is rated at 525 horsepower at 1,900 r. p. m. and is still one of the most used of the larger-powered radial air-cooled engines.

This company has also developed the Wasp Junior engine, which is rated at 300 horsepower at 2,000 r. p. m.

The Curtiss Aeroplane & Motor Co. has continued the development of the Chieftain (H-1640). This is a 12-cylinder 2-row radial engine rated at 600 horsepower at 2,200 r. p. m. The arrangement of providing two rows of cylinders and a 2-throw crank shaft makes possible the reduction of the overall diameter and the elimination of the counterweight that is required on all single-throw crank shafts for fixed radial engines.

The Curtiss Challenger (R-600) engine is a 6-cylinder radial, having two rows of three cylinders each, with the cylinders staggered. This engine is still largely used in commercial aircraft. During the past year the Challenger and the Chieftain engines have undergone minor refinement which has led to greater reliability.

The Wright V-1460, 12-cylinder inverted V-type air-cooled engine has been rated between 480 and 500 horsepower at 2,000 r. p. m. The cylinder dimensions are 4 $\frac{7}{8}$ -inch bore and 6 $\frac{1}{2}$ -inch stroke, with a piston displacement of 1,456 cubic inches.

In the series of radial air-cooled engines developed by the Wright Aeronautical Corporation known as the J-6 series there are three engines, a 5-cylinder engine rated at 165 horsepower at 2,000 r. p. m., a 7-cylinder engine rated at 240 horsepower at 2,000 r. p. m., and a 9-cylinder engine rated at 300 horsepower at 2,000 r. p. m. In the development of the J-6 series the Wright Aeronautical Corporation has kept in mind the advantages of interchangeability of parts.

The Wright Cyclone engine, known as the R-1750-A, has been superseded by the R-1820-E, which is a 9-cylinder radial engine rated at 575 horsepower at 1,900 r. p. m. This engine is being used by the Navy

Department as standard equipment for some of the larger-type service airplanes and seaplanes.

The Packard Motor Car Co. has concentrated development work on the compression-ignition engine, and during the past year material progress has been made in the reduction of smoke and in smoothing out the operation. This engine has already been used in commercial aircraft. Other companies interested in the development of compression-ignition oil engines for aircraft purposes are the Allison Engineering Co. and the Westinghouse Electric & Manufacturing Co.

The following is a list of the engines which have received approved-type certificates issued by the Department of Commerce. In all there are 64 engines now available, and the majority of them are of the radial air-cooled type having either 5, 7, or 9 cylinders. It is interesting to note that in this group there are 39 engines covering a wide variation of horsepowers, ranging from 65 to 575.

<i>Inverted 4-cylinder in-line air-cooled:</i>	Hp.	R. p. m.
Michigan Rover.....	55	1,900
Michigan Rover.....	75	1,975
Wright Gipsy L-320.....	90	1,950
Chevrolair D-4.....	90	2,000
Menasco Pirate A-4.....	90	1,925
Chevrolet Model 333.....	120	2,100

<i>Four-cylinder in-line air-cooled:</i>	Hp.	R. p. m.
American Cirrus Mark III.....	90	2,100
American Cirrus Hidrive.....	95	2,100
Dayton Bear.....	100	1,500
American Cirrus Mark III, supercharged.....	110	2,100

<i>Six-cylinder in-line air-cooled inverted:</i>	Hp.	R. p. m.
Fairchild 6-390.....	120	2,150
Chevrolair D-6.....	165	2,175

<i>Eight-cylinder V air-cooled:</i>	Hp.	R. p. m.
Milwaukee Tank 502 (V-470).....	115	1,650

<i>Three-cylinder radial air-cooled:</i>	Hp.	R. p. m.
Szekely SR-3.....	30	1,750

<i>Four-cylinder radial air-cooled:</i>	Hp.	R. p. m.
Fairchild Caminez 447-C.....	120	960

<i>Five-cylinder radial air-cooled:</i>	Hp.	R. p. m.
Lambert Velie M-5 (R-250).....	65	1,900
LeBlond 60 (5D).....	65	1,950
LeBlond 70 (5DE).....	70	1,950
LeBlond 85 (5DF).....	85	2,125
Warner Scarab.....	90	2,025
Lambert R-266.....	90	2,375
Kinner K-5.....	100	1,810
General Airmotors Moore.....	120	1,600
Kinner B-5 (R-440).....	125	1,925
Wright J-6 R-540.....	165	2,000
Kinner C-5 Model (R-715).....	210	1,900

<i>Six-cylinder radial air-cooled:</i>	Hp.	R. p. m.
Brownback Tiger C-400	90	1,700
Curtiss Challenger R-600	185	2,000

<i>Seven-cylinder radial air-cooled:</i>		
LeBlond 90 (7D)	90	1,975
LeBlond 110 (7DF)	110	2,150
Warner Scarab	110	1,850
Alliance Hess Warrior	115	1,925
Axelsson	115	1,800
Kimball Beetle K	120	1,850
Aircraft Comet	130	1,825
Western L-7	130	1,850
Jacobs LA-1	140	1,800
MacClatchie Panther Model X-2	150	1,900
Comet Model 7-E	165	1,900
Continental A-70	165	2,000
Wright J-6 R-760	240	2,000

<i>Nine-cylinder radial air-cooled:</i>		
Aeromarine Rad B	115	1,925
Lycoming R-645	185	2,000
Lycoming R-680	215	2,000
Wright J-5 Whirlwind	220	2,000
Wright J-6 R-975	300	2,000
Pratt & Whitney Wasp Jr	300	2,000
Wright R-975-C (10.15:1, impeller gears)	400	2,300
Pratt & Whitney R-1340-C Wasp	420	2,000
Pratt & Whitney 4-1340-C (geared)	425	2,050
Pratt & Whitney SC (10:1, impeller gears)	450	2,100
Pratt & Whitney R-1690-A, geared 2:1	500	1,900
Pratt & Whitney Hornet	525	1,900
Wright Cyclone R-1750-A	525	1,900
Pratt & Whitney R-1860, Series B	575	1,950
Wright Cyclone Model R-1820-E	575	1,900

<i>Twelve-cylinder radial air-cooled:</i>		
Curtiss Chieftain H-1640	600	2,200

<i>Eight-cylinder V water-cooled:</i>		
Arnold Harris	90	1,400

<i>Twelve-cylinder V water-cooled:</i>		
Curtiss D-12	435	2,300
Packard 3A-1500, direct	525	2,100
Curtiss Conqueror V-1550	600	2,400
Curtiss Conqueror GV-1570, geared	600	2,400
Packard 3A-2500, direct	800	2,000

<i>Compression-ignition:</i>		
Packard DR-980	225	1,950

## REPORT OF COMMITTEE ON MATERIALS FOR AIRCRAFT

## ORGANIZATION

The present organization of the committee on materials for aircraft is as follows:

Dr. George K. Burgess, Bureau of Standards, chairman.  
 Prof. H. L. Whittemore, Bureau of Standards, vice chairman and acting secretary.  
 Lieut. R. S. Barnaby (C. C.), United States Navy.  
 S. K. Colby, United States Aluminum Co.  
 Warren E. Emley, Bureau of Standards.  
 Commander Garland Fulton (C. C.), United States Navy.  
 Henry A. Gardner, Institute of Paint and Varnish Research.  
 Dr. H. W. Gillett, Battelle Memorial Institute.  
 Prof. George B. Haven, Massachusetts Institute of Technology.  
 C. H. Helms, National Advisory Committee for Aeronautics.  
 Zay Jeffries, Aluminum Co. of America.  
 J. B. Johnson, matériel division, Army Air Corps, Wright Field.  
 George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).  
 Lieut. Alfred J. Lyon, United States Army, matériel division, Air Corps, Wright Field.  
 Lieut. Commander H. R. Oster (C. C.), United States Navy.  
 H. S. Rawdon, Bureau of Standards.  
 E. C. Smith, Central Alloy Steel Corporation.  
 G. W. Trayer, Forest Products Laboratory, Forest Service.  
 Starr Truscott, National Advisory Committee for Aeronautics.  
 Hon. Edward P. Warner, editor of "Aviation."

## FUNCTIONS

Following is a statement of the functions of the committee on materials for aircraft:

1. To aid in determining the problems relating to materials for aircraft to be solved experimentally by governmental and private agencies.
2. To endeavor to coordinate, by counsel and suggestion, the research and experimental work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding investigation of materials for aircraft in progress or proposed.
4. To direct and conduct research and experiment on materials for aircraft in such laboratory or laboratories, either in whole or in part, as may be placed under its direction.

5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

The committee on materials for aircraft, through its personnel acting as a medium for the interchange of information regarding investigations on materials for aircraft, is enabled to keep in close touch with research in this field of aircraft development. Much of the research, especially in the development of light alloys, must necessarily be conducted by the manufacturers interested in the particular problems, and both the aluminum and steel industries are represented on the committee. In order to cover effectively the large and varied field of research on materials for aircraft four subcommittees have been formed, as follows:

*Subcommittee on metals:*

H. S. Rawdon, Bureau of Standards, chairman.  
 Dr. H. W. Gillett, Battelle Memorial Institute.  
 Zay Jeffries, Aluminum Co. of America.  
 J. B. Johnson, matériel division, Army Air Corps, Wright Field.  
 George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).  
 E. C. Smith, Central Alloy Steel Corporation.  
 Starr Truscott, National Advisory Committee for Aeronautics.  
 Prof. H. L. Whittemore, Bureau of Standards.

*Subcommittee on woods and glues:*

G. W. Trayer, Forest Products Laboratory, Forest Service, chairman.  
 H. S. Betts, Forest Service.  
 George W. Lewis (ex officio member).  
 Prof. H. L. Whittemore, Bureau of Standards.

*Subcommittee on coverings, dopes, and protective coatings:*

C. H. Helms, National Advisory Committee for Aeronautics, chairman.  
 Dr. W. Blum, Bureau of Standards.  
 Warren E. Emley, Bureau of Standards.  
 Henry A. Gardner, Institute of Paint and Varnish Research.  
 Prof. George B. Haven, Massachusetts Institute of Technology.  
 George W. Lewis (ex officio member).  
 James E. Sullivan, Bureau of Aeronautics, Navy Department.  
 P. H. Walker, Bureau of Standards.  
 E. R. Weaver, Bureau of Standards.

*Subcommittee on aircraft structures:*

Starr Truscott, National Advisory Committee for Aeronautics, chairman.  
 Lieut. C. E. Archer, United States Army.  
 C. P. Burgess, Bureau of Aeronautics, Navy Department.

Richard Gazley, Aeronautics Branch, Department of Commerce.

Capt. Carl F. Greene, United States Army, matériel division, Air Corps, Wright Field.

Charles Ward Hall, Hall-Aluminum Aircraft Corporation.

Lieut. Lloyd Harrison (C. C.), United States Navy.

George W. Lewis (ex officio member).

Lieut. R. D. MacCart (C. C.), United States Navy.

Charles J. McCarthy, Chance Vought Corporation.

Prof. J. S. Newell, Massachusetts Institute of Technology.

Dr. L. B. Tuckerman, Bureau of Standards.

Much of the research in connection with the development of materials for aircraft is financed directly by the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, and the National Advisory Committee for Aeronautics, and many of the problems are apportioned to the Bureau of Standards for investigation.

#### MEETINGS OF THE COMMITTEE

Meetings of the committee were held several times during the year to consider reports on the work being conducted by the subcommittees. Particular attention was given the continuation of work on the development of methods for protecting light alloys, particularly duralumin, from corrosion. This work was begun some years ago and has always formed a major subject for investigation.

#### SUBCOMMITTEE ON METALS

The study of the properties of metals as related to their application to aircraft construction has been carried out at the Bureau of Standards, in cooperation with the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, and the National Advisory Committee for Aeronautics. Special attention has been given to the subject of the permanence under service conditions of the light alloys which in wrought form are used for structural purposes. The study of the corrosion resistance of the duralumin type of alloy has been continued and marked progress has been made in the development of suitable protective measures to be observed in its use. The study of its endurance under fatigue stresses has also been continued and tentative values for its fatigue resistance have been obtained.

*Intercrystalline embrittlement of sheet duralumin—Weather-exposure tests.*—The exposure tests at Coco Solo, Hampton Roads, and Washington have been continued—this year being the third of the 5-year program. Although the tests have already definitely dem-

onstrated that embrittlement by corrosion can be expected to occur in sheet material which has been heat-treated by being quenched in hot water, conclusive evidence is as yet lacking that material heat-treated by being quenched in cold water may not show the same deterioration when sufficient time has elapsed. Hence the necessity for continuing the tests for the 5-year period initially planned. So far, however, the 0.083-inch sheet material which was quenched in cold water has shown practically no susceptibility to deterioration of this kind under the conditions encountered in the exposure tests.

The rate of corrosive attack of the specimens for practically all the materials exposed becomes much lower as time elapses. The initial rate, that is, during the first year, for those materials which showed marked susceptibility to intercrystalline attack was much higher than that of the past year. The more pronounced rate of embrittlement is shown by duralumin which has been aged at an elevated temperature. This is true regardless of the method of quenching used.

These exposure tests indicate that none of the coatings which have been tested is 100 per cent satisfactory. However, those pigmented with aluminum and those consisting of linseed oil pigmented with carbon black or iron oxide and zinc chromate have proved superior to the others.

Methods of improving the adherence of the coating to the base metal and thus increasing the protection have been studied in the laboratory. The use of the anodic treatment on duralumin prior to the application of a coating (such as aluminum-pigmented spar varnish) has proven very effective. Even under very severe corrosive conditions, such as corrosion accompanied by repeated flexural stressing of the material, the advantage to be gained by applying coatings in this way is very evident.

Exposure tests of thin sheet duralumin (0.008 inch) and Alclad duralumin (0.010 inch), in which the tension specimens were cut from the sheet after exposure have continued to show the marked advantage of the aluminum-coated sheet over plain duralumin. The decrease in the tensile properties of each, however, is more marked than is shown by thicker material such as 0.083-inch sheet exposed for the same period.

*Exposure tests of magnesium and magnesium alloys.*—Exposure tests of sheet materials and cast bars were started at Coco Solo, Canal Zone, and at Washington, the general method and scope of the work being similar to that used in the similar tests on duralumin. It was found necessary to discontinue the tests at Coco Solo after a few months on account of the marked "crevice corrosion" which occurred where the specimens were attached to the rack.

None of the protective coatings used afforded high resistance to crevice corrosion. The specimens exposed at Washington are still under observation. Many of the specimens are showing flaking of the coating after one year's exposure to the weather. In many cases the flaking is very marked. In general, however, the change in the tensile properties of the metal has not been nearly so pronounced as the change in the condition of the coating.

*High-frequency fatigue tests of light alloy sheet material.*—The set-up of air-driven high-frequency fatigue testing machines at the Bureau of Standards now comprises seven units, which are in operation 15 hours each day. The machines are so arranged that they are readily convertible for specimens which have either a 5 or 6 inch nodal distance and which vibrate at frequencies of 310 and 215 cycles per second, respectively.

Extreme fiber stresses up to 24,000 pounds per square inch are obtainable with these machines.

The investigation of the fatigue properties of a series of the aluminum and magnesium alloys has been continued, and it is hoped that this part of the program will be completed by January 1, 1931. It is planned then to start a series of tests on welded specimens having the weld at the center of the bar.

At the present time tests have been completed on the longitudinal specimens of seven of the materials and on the transverse specimens of three of the materials under consideration. Longitudinal specimens are cut with the longest dimension in the direction of rolling. Transverse specimens have the longest dimension at right angles to the direction of rolling.

Below is given a list of the materials and their endurance limits as determined by the tests:

*Longitudinal and transverse specimens*

MATERIAL	ENDURANCE LIMIT
MAH 4 per cent aluminum, 0.4 per cent manganese, balance magnesium as rolled	Pounds per square inch 5,000-6,000
2SH Commercially pure aluminum, cold-rolled	10,000
3SH 1.25 per cent manganese, balance aluminum, cold-rolled	12,000

*Longitudinal specimens*

17ST "Duralumin," 4 per cent copper, 0.5 per cent manganese, 0.5 per cent magnesium, balance aluminum, quenched and aged	15,000
25SW 4.5 per cent copper, 0.8 per cent manganese, 0.8 per cent silicon, balance aluminum, quenched and aged	11,000

MATERIAL	ENDURANCE LIMIT
<i>Longitudinal specimens</i> —Continued	
51SW 0.6 per cent magnesium, 1 per cent silicon, balance aluminum, quenched and aged -----	10,500
51ST 0.6 per cent magnesium, 1 per cent silicon, balance aluminum, quenched and aged -----	13,000

*Fatigue of Alclad duralumin.*—The comparative flexural fatigue tests on corroded and uncorroded Alclad duralumin, in cooperation with the Aluminum Co. of America, have been continued.

Confirming the results reported last year, the tests indicate that the corrosion of the Alclad specimens has not appreciably decreased their endurance under alternating stress. The corroded duralumin specimens, however, showed a definite lowering of their resistance to alternating stress as the corrosion increased.

*Identification of carbon-steel and chromium-molybdenum steel airplane tubing.*—Both carbon-steel and chromium-molybdenum steel tubing are widely used in the structures of airplanes. Although they have markedly different physical properties, they can not be distinguished by visual inspection and often become mixed.

During the year a study was made of methods for distinguishing between these two kinds of steel tubing. The study was of an exploratory nature, the aim being to find rapid nondestructive tests for establishing the identity of these two kinds of tubing when mixed.

The results of the laboratory study have been summarized for publication in Technical Note No. 850. In brief, these results show that a magnetic method based upon coercive force is entirely feasible for this purpose.

A method already in current use in the mill depends upon the determination of hardness by the Rockwell method. The National Advisory Committee for Aeronautics has issued a Technical Note (No. 342) describing this method. Methods depending upon other kinds of hardness tests than the Rockwell are not so reliable and dependable as the method already in use.

By means of the spark test, tubes can be very readily sorted. With the use of a high-speed abrasive wheel to produce the sparks the damage to the surface appears to be negligible. Skill in the use of this method can be very readily acquired.

At present there is no simple and reliable chemical "spot" test for the chromium-molybdenum steel as there is for nickel steel. Further study is necessary and the current work is being directed along this particular line.

#### SUBCOMMITTEE ON WOODS AND GLUES

During the past year the work has consisted chiefly in the preparation of reports on the investigations previously conducted. Four of these reports have been published as Technical Reports of the committee. The final one is in preparation and will be published shortly.

The reports published are as follows:

No. 334, "The Torsion of Members Having Sections Common in Aircraft Construction," by George W. Trayer and H. W. March.

No. 344, "Design of Plywood Webs for Airplane Wing Beams," by George W. Trayer.

No. 345, "Design of Airplane Wing Ribs," by J. A. Newlin and George W. Trayer.

No. 347, "A Method of Calculating the Ultimate Strength of Continuous Beams," by J. A. Newlin and George W. Trayer.

The final report now in preparation is on the subject of failure due to elastic instability, including the wrinkling of thin outstanding flanges, the twisting of compression members with thin outstanding parts, and the lateral buckling of beams. It is felt that the report will be valuable in connection with metals as well as with wood.

#### SUBCOMMITTEE ON COVERINGS, DOPES, AND PROTECTIVE COATINGS

Much of the work on the development of coverings, dopes, and protective coatings is carried on at the Bureau of Standards and by the matériel division of the Army Air Corps and the Naval Aircraft Factory.

*Gas cell fabrics.*—One problem that has been continued during the year is the development of a satisfactory substitute for goldbeater's skin fabric. A material consisting of a mixture of viscose and latex provided very good results in the laboratory, but when made up into gas cells and placed in the *Los Angeles* it did not have sufficient durability to compete with goldbeater's skin fabric. It was believed that the manufacturing process was responsible. Three other attempts were made by other manufacturers to produce a satisfactory viscose-latex fabric and all three were failures.

Another type of fabric consists of rubberized cloth on which are spread several layers of a glycerin-latex mixture. Two gas cells have been constructed of this fabric, one of which has been in the *Los Angeles* for nine months and the other seven months. These cells have stood up very well and appear to meet the requirements in all respects. The cost of this type of fabric is approximately one-half that of the viscose latex or of goldbeater's skin, and its diffusion to helium is slightly more. It is proposed that half of the gas



cells of the new airship now being built for the United States Navy shall be of this fabric.

*Protective coatings for duralumin and magnesium.*—Exposure tests of coatings for aluminum and magnesium alloys have been continued in cooperation with the subcommittee on metals. The test specimens have been exposed at Coco Solo, Canal Zone, at Hampton Roads, Va., and at the Bureau of Standards. Physical tests are made of the specimens after exposure to determine the change in properties due to corrosive attack. The coatings which have given the best protection are spar varnish pigmented with aluminum powder and carbon black or iron oxide-zinc chromate in a vehicle of linseed oil.

*Substitute for silk cloth for parachutes.*—The experimental cotton cloths developed in this investigation, together with two commercial ones, were made up into parachutes and given drop tests by the naval air station at Lakehurst, N. J. The data obtained from these tests clearly indicate that the cotton-cloth parachute closely approaches the silk parachute in performance as to rate of descent, opening time, strength, and ability to function when stored in the packed condition for 60 days. The cotton cloth, however, increased the weight of the equipment from 18 to 19 pounds. This increase in weight is well within practicable limits.

As cotton parachutes have been in use for some time by commercial aviators on account of their lower cost, the results obtained from this investigation will be reassuring to them, while the military services, which use silk exclusively, are assured of a domestic source of supply in case of emergency.

The investigation is practically completed and a report of the entire work is in preparation. However, before the work is concluded another parachute will be fabricated from yarns and cloth, spun and woven in accordance with the data so far obtained.

During the year Technical Note No. 335, entitled "The Structure and Properties of Parachute Cloths," by H. J. McNichols and A. F. Hedrick, was published. This note also contains a description of a machine for measuring the elastic properties of cloth under flexure and information as to the effect of the weave on the tearing resistance.

*Study of mercerization of cotton for aeronautical uses.*—The broad purpose of this investigation is the improvement of domestic cotton textiles for aeronautical uses. One of the principal requirements of airplane wing-cover cloth, balloon cloths, parachute cloth, webbings, etc., is maximum strength for a given weight. The strength-weight ratio for cotton yarns and cloths depends primarily upon the kind of staple, length of the cotton, the size, twist, and ply of the yarn, and the mercerization process. Of these, mercerization especially requires investigation, because ordinary commercial mercerization is concerned with

luster and appearance rather than with increase in strength-weight ratio. Isolated experiments indicate that mercerization may result in an increase of 40 or 50 per cent in the strength-weight ratio, but the optimum conditions for obtaining the maximum increase are not known. It is the object of this investigation to make a systematic study of mercerization from the point of view of domestic cotton aeronautical textiles.

It is believed that significant progress in the development of aeronautical textiles in the United States will result from an increase in the strength-weight ratio of cotton cloths, and it is probable that such an increase can be obtained through a study of the mercerization process.

In the study of the mercerization process there appear to be four factors which affect the properties of the yarn. These are the tension of the yarn during mercerization, the strength of the alkali used, the temperature maintained during the process, and the time.

An apparatus has been designed and is now being built in which a skein of yarn may be placed and these factors definitely established and studied.

#### SUBCOMMITTEE ON AIRCRAFT STRUCTURES

Practically all the investigations under the cognizance of this subcommittee are conducted at the Bureau of Standards. These investigations are undertaken at the request of the Aeronautics Branch of the Department of Commerce, the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, or the National Advisory Committee for Aeronautics. Some of the more important investigations in progress or completed during the past year are outlined below.

*Strength of welded joints in tubular members for aircraft.*—The results of the first series of tests made for the Aeronautics Branch of the Department of Commerce on some 165 welded joints have been published by the National Advisory Committee for Aeronautics as Technical Report No. 348. Work has been started on a second program sponsored by the National Advisory Committee for Aeronautics in which (1) several new types of joints developed from information obtained from the first series will be tested, and (2) an investigation of the conditions which produce high residual stresses and cracking in welded members will be made.

Among the joints which will be tested (part 1) are: Type of lattice joint reinforced by an inserted gusset cut away between the tubes, which it is believed should give lower residual stresses than the previous type; a lattice joint having more intersecting tubes than the types previously tested; and T and lattice joints loaded in such a way as to cause bending stresses in the tubes at the weld.



The previous investigation showed that the strength of a lattice joint could be increased about 20 per cent by welding a gusset plate into the joint. It is believed that greater strength will be obtained if the residual stresses are negligible in the specimen. In order to study the conditions producing such stresses (part 2) an attempt will be made to determine at least approximately the stresses produced in gusset plates and to measure the displacements of the members of several typical joints resulting from the welding operation.

*Form factors for tubing of duralumin and steel under combined column and beam loads.*—The tubing used in the original program covered a somewhat limited range of wall thicknesses and of outside diameters. The results of the experiments on these tubes were used in the preparation of a series of design charts (Technical Note No. 307 of the National Advisory Committee for Aeronautics). From these charts the strength of duralumin and of chromium-molybdenum steel tubes under various combinations of axial compression and transverse loads may be obtained. These apply to materials which comply with Army-Navy Specification No. AN-9092 (1929 issue) for duralumin and Army Air Service Specification No. 10231-B, June 21, 1926, for chromium-molybdenum steel. During the past year the program was considerably extended to include tubes of both duralumin and chromium-molybdenum steel having outside diameters of 1 inch, 1½ inch, and 2 inches and having ratios of outside diameter to wall thickness ranging from about 15 to 60.

All the experimental work on the duralumin tubes has been completed. The experimental work on the chromium-molybdenum steel tubes will in all probability be completed by the end of this calendar year. Charts similar to those in Technical Note No. 307 will be drawn for all of the tubes.

There is sufficient evidence to indicate that this method of presenting the results can be used satisfactorily for the other tubes which are being tested.

The maximum ratio of the outside diameter to the wall thickness of tubes which can be obtained commercially at present is about 60. There is little doubt that with improvements in the methods of manufacture tubes having a greater ratio of diameter to wall thickness will be commercially available. The advantages of using tubes having a high value of this ratio make it extremely desirable to have accurate information on the strength of such tubes.

The study of the relationship between the tensile properties and modulus of rupture of duralumin and chromium-molybdenum tubing has been continued as much as possible without interfering with the remainder of the program but no definite results have been obtained.

As the relations are not simple, no satisfactory answer can be expected without considerably more research.

*Airship girders and airship structural members.*—The method of obtaining the minimum cross-sectional areas of girders of nonuniform cross section has been developed until it can be considered a routine procedure.

A girder of this type 5 meters long and several latticed girders (*Los Angeles* type) have been tested in compression.

Terminal loops as used in the bracing wires of the U. S. S. *Los Angeles* were tested to determine their behavior under varying load. If the wire was not preformed it was found that relatively low tensile loads caused high flexural stresses in the loops. These tests have been extended to include the investigation of preformed loops having small radii which were developed by the Goodyear-Zeppelin Corporation. These tests are in progress.

In connection with the annual survey to determine the condition of the U. S. S. *Los Angeles*, about 230 samples of channel and lattice material were tested. Although the tests indicated a slow progress in the corrosion since the previous sampling, no sample was found in which the corrosion had progressed enough to reduce the strength of the girders below the designed values.

*End fixation of struts.*—Compression members in aircraft are usually not "pin-ended," nor are they completely "fixed." A condition between these commonly prevails; the end actually rotates under load and is acted on by a restraining couple which is proportional to the amount of this rotation. At the request of the Bureau of Aeronautics, the Bureau of Standards is attempting a quantitative evaluation of the strength afforded by various degrees of fixation.

The technique of testing has reached a satisfactory stage of development. The partial fixation of the ends is simulated in a testing machine by casting Wood's metal around the ends of the test specimen set in steel cups. The cup at each end fits securely into a test fixture which is seated on a knife edge, and as a compressive load is applied the fixture rotates about the knife edge. The amount of this rotation is controlled by means of two helical springs which act against arms extending from the fixture at right angles to the knife edge. By varying the number of active coils in the springs the degree of end restraint can be controlled.

A complete series of chromium-molybdenum tubes, 1½ inches in diameter and 0.058 inch thick, has been tested with free ends, and also another series of similar tubes with a restraint of 132,000 pounds-inch per

radian of rotation of the fixture at each end was tested. The slenderness ratios varied from about 30 to 150. Each specimen was tested in duplicate, and the results were found to agree satisfactorily.

Apparatus is being prepared for another series of tests with tubes of the same kind and size as those already tested but with greater end restraint.

*Technique of testing flat plates under normal pressure.*—The large-sized apparatus for this investigation was completed during the past year and tested on sample plates covering the extreme sizes.

This apparatus can be used for testing specimens from  $2\frac{1}{2}$  inches square up to 30 by 90 inches.

In consultation with the Bureau of Aeronautics, a program of tests on unsupported flat plates of 17-ST duralumin in the sizes used in seaplane construction has been prepared. The tests will be started as soon as the material is received.

Upon completion of the tests on unsupported plates it is planned to test plates reinforced by ribs and other stiffeners.

*Inelastic behavior of duralumin and alloy steels in tension and compression.*—Because of testing difficulties, practically all materials are bought on the basis of their properties as determined by tensile tests. The fact that low compressive strengths have sometimes been obtained for cold-worked tubing purchased under specifications which gave requirements for the tensile properties only, makes it desirable to determine the relation between the tensile and compressive properties of tubing of different materials.

At the request of the Bureau of Aeronautics of the Navy Department and the National Advisory Committee for Aeronautics, compressive and tensile tests are being made on tubes and on typical sections used for the chord members of airship girders. Compressive and tensile tests of specimens cut from flat sheets will also be made.

For these tests 1-inch Tuckerman optical strain gages are being designed so that specimens  $1\frac{1}{2}$  inches long can be used for the compressive tests.

*Torsional strength of tubing.*—The data available to the aircraft designer on the torsional strength of thin-walled tubes are not sufficiently complete for design purposes. Such tubes are used for the axes of rotation of control surfaces of airplanes and are subjected under some conditions to high torsional stresses.

At the request of the Bureau of Aeronautics, Navy Department, approved by the National Advisory Committee for Aeronautics, an investigation of the torsional strength of thin-walled tubing has been undertaken. Both duralumin and chromium-molybdenum steel tubes are included in the program. The former have both circular and noncircular cross sections ("built-up" sections), and the latter have only circu-

lar sections. These are the materials and sections which are most widely used at the present time in aircraft construction.

The torsional properties of the tubes, proportional limit or yield point, and ultimate strength in torsion will be determined for a number of tubes having outside diameters from three-fourths to 2 inches and wall thicknesses from 0.03 to 0.12 inch.

The experimental work on the first series of tests is in progress. Apparatus and methods of testing have been worked out which so far as can be judged at this time will give satisfactory results. The tests of about 20 chromium-molybdenum steel tubes have been completed.

The way in which the specimens fail will be carefully studied in an attempt to determine that wall thickness, for each diameter and material, below which the tube fails by collapse due to critical instability and above which the tube fails by shear.

## REPORT OF COMMITTEE ON PROBLEMS OF AIR NAVIGATION

### ORGANIZATION

In response to the need for the coordination of scientific research being conducted by a number of different agencies, both within and without the Government, on the problems of air navigation, particularly in the fields of navigation instruments, aerial communications, and meteorological problems, the National Advisory Committee for Aeronautics in 1928 established a new standing committee on problems of air navigation, with members representing the principal agencies concerned with the development of aids to air navigation.

The committee on problems of air navigation is at present composed of the following members:

- Hon. William P. MacCracken, jr., chairman.
- Dr. L. J. Briggs, Bureau of Standards.
- Lloyd Espenschied, American Telephone & Telegraph Co.
- Brig. Gen. B. D. Foulois, United States Army, Air Corps, War Department.
- Paul Henderson, National Air Transport (Inc.).
- Capt. S. C. Hooper, United States Navy, Director of Naval Communications, Navy Department.
- Dr. J. C. Hunsaker, Goodyear-Zeppelin Corporation.
- George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
- Col. Charles A. Lindbergh.
- Prof. Charles F. Marvin, Weather Bureau.
- C. M. Young, Assistant Secretary of Commerce for Aeronautics.

## FUNCTIONS

The functions of the committee on problems of air navigation are as follows:

1. To determine the problems in the field of air navigation that are most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of approved problems.
3. To act as a medium for the interchange of information regarding investigations and developments in air navigation, in progress or proposed.
4. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

In order to cover effectively the large and varied field of research and development on problems of air navigation, subcommittees on problems of communication, on instruments, and on meteorological problems have been organized under the committee on problems of air navigation.

## SUBCOMMITTEE ON PROBLEMS OF COMMUNICATION

The membership of the subcommittee on problems of communication is as follows:

- Lloyd Espenschied, American Telephone & Telegraph Co., chairman.
- Dr. J. C. Hunsaker, Goodyear-Zeppelin Corporation, vice chairman.
- C. H. Helms, National Advisory Committee for Aeronautics, secretary.
- Maj. William R. Blair, United States Army, Signal Corps, War Department.
- Dr. J. H. Dellinger, Bureau of Standards.
- George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
- W. G. Logue, Radiomarine Corporation of America.
- J. L. McQuarrie, International Telephone & Telegraph Co.
- Lieut. Commander Joseph R. Redman, United States Navy, Office of the Director of Naval Communications, Navy Department.
- Eugene Sibley, Aeronautics Branch, Department of Commerce.

The work of the subcommittee during the past year centered on the discussion of the important problems of radio communication which have a direct bearing on the navigation of aircraft with a view to determining what fundamental research is desirable to further progress along these lines.

The United States is rapidly establishing a comprehensive system of airways involving operation over both land and water. The safety of the navigation of aircraft over these airways is greatly dependent upon

the use of radio systems. Radio directional and communication systems are being provided extensively not only in the commercial field but by the military services of the Government as well.

The United States, in common with other countries, is therefore in the position of building up a large system of air transport, dependent to a considerable extent upon radio, without there being available a quantitative knowledge of the radio-transmitting medium between ground and aircraft upon which to base the design of the necessary communication systems. The transmission conditions may be expected to vary between day and night, different seasons of the year, and between different air routes. If no study were made of these conditions, a certain amount of general knowledge would be obtained in the course of events as a result of experience, but this knowledge would be quite inadequate as a basis on which to design reliable radio-communication systems.

These radio developments have had to go forward in advance of definite knowledge as to the characteristics of the radio-transmitting medium between ground and airplane as to what frequencies are best for a given type of service and as to the range and reliability of the various frequencies. The relatively low-frequency waves employed by the beacons are reasonably reliable for moderate distances, but the range of these waves to aircraft for reliable reception and also in respect to interference with distant beacons is not very definitely determined. The higher frequencies (short waves) used for 2-way communication are erratic and therefore less reliable, and relatively little quantitative data on their characteristics in respect to aircraft use are available.

Recognizing the need of fundamental data on the characteristics of the transmission medium over the airways of the country, the National Advisory Committee for Aeronautics, on recommendation of the subcommittee on problems of communication, has invited attention to the need for a quantitative survey of radio transmission to and from aircraft. The proposal has received the indorsement of the Secretaries of War, Navy, and Commerce. Under their cognizance this survey is to be planned and directed, and will be prosecuted by the Aeronautics Branch of the Department of Commerce in connection with current investigations of radio-communication methods to develop air-navigation facilities.

## SUBCOMMITTEE ON INSTRUMENTS

The subcommittee on instruments is at present organized as follows:

- Dr. L. J. Briggs, Bureau of Standards, chairman.
- Marshall S. Boggs, Aeronautics Branch, Department of Commerce.

Dr. W. G. Brombacher, Bureau of Standards.  
 Dr. Samuel Burka, Dayton, Ohio.  
 C. H. Colvin, Society of Automotive Engineers.  
 Lieut. A. F. Hegenberger, United States Army,  
 Matériel Division, Air Corps, Wright Field.  
 Dr. A. W. Hull, General Electric Co.  
 Carl W. Keuffel, Keuffel & Esser.  
 George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).  
 Lieut. T. C. Lonnquest, United States Navy,  
 Bureau of Aeronautics, Navy Department.  
 H. J. E. Reid, National Advisory Committee for Aeronautics.

A number of the investigations in connection with the development of instruments for air navigation are conducted by the Bureau of Standards in cooperation with the Bureau of Aeronautics of the Navy, the Army Air Corps, and the National Advisory Committee for Aeronautics. These investigations have been carried out under the cognizance of the committee on aerodynamics and are outlined in the report of that committee. Among the investigations under way during the past year are the determination of the temperature coefficient of the elastic moduli of diaphragm and spring materials for aircraft instruments; study of the friction of pivots in bearings; survey of the present status of the measurement of speed on aircraft; and investigation of damping liquids for aircraft instruments.

*Report on present status of aircraft instruments.*—In accordance with request of the committee on problems of air navigation, the subcommittee on instruments has been engaged in a general survey of the field of air navigation instruments, and has prepared a summary of the present status of aircraft instrument development. This summary will be published as Technical Report No. 371 of the National Advisory Committee. It was believed inadvisable to limit the scope of this report to a consideration of the class of instruments ordinarily called air-navigation instruments, because the safe operation of an aircraft may depend as well upon the satisfactory performance of other aircraft instruments. The scope of the report was accordingly enlarged to include aircraft instruments in general. The report contains sections on speed, altitude, navigation, power plant, oxygen, and fog-flying instruments, and summarizes the instrument problems existing at the present time. The most important of these problems are those relating to navigation in fog and to landing during fog and other conditions of poor visibility, the satisfactory solution of which will probably depend largely on the use and development of radio equipment and special instruments.

#### SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

The membership of the subcommittee on meteorological problems is as follows:

Prof. Charles F. Marvin, Weather Bureau, chairman.  
 Thomas H. Chapman, Aeronautics Branch, Department of Commerce.  
 W. R. Gregg, Weather Bureau.  
 Dr. W. J. Humphreys, Weather Bureau.  
 Dr. J. C. Hunsaker, Goodyear-Zeppelin Corporation.  
 George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).  
 Lieut. F. W. Reichelderfer, United States Navy, naval air station, Lakehurst.  
 Dr. C. G. Rossby, Massachusetts Institute of Technology.  
 Capt. Bertram J. Sherry, United States Army, Signal Corps, War Department.

The principal agency engaged in the study of meteorological problems as related to air navigation is the Weather Bureau. However, practically every organization concerned with the operation of aircraft is interested in problems of this nature, and studies along this line have been conducted by the Signal Corps and Air Corps of the Army and the Bureau of Aeronautics of the Navy in connection with the operation of aircraft.

The chief problems which have received consideration by the subcommittee on meteorological problems during the past year are the structure of the atmosphere, particularly wind gustiness; fog and fog dispersal; and ice formation on aircraft in flight.

*Methods for measurement of air gusts.*—A study has been made at the Weather Bureau of methods for the measurement of fluctuations of wind velocity. As a result of this study the conclusion has been reached that the cup anemometer is best suited for this purpose, surpassing all other velocity-measuring apparatus in simplicity, sturdiness, durability, stability of calibration constants, absence of material friction, instant response to winds from any azimuth, and facility with which indications can be transmitted any reasonable distance.

In order to realize to the full the advantages of the cup anemometer, adequate means of registration are required. After a study of the entire problem and examination of numerous possible methods of registration, the Friez cup anemometer, which is of the electro-magnetic type, was adopted, in conjunction with an Esterline-Angus galvanometer for registration purposes. Records are made on a moving band of paper, yielding curved lines for the time scale. In order to secure accelerations from these record sheets, a special celluloid scale was devised, on which numerous curved

lines represent a scale of increasing accelerations by suitable units. This scale when placed over the record sheet permits the evaluation in a highly satisfactory manner of the accelerations at various points on the record.

With this measuring apparatus steady accelerations—that is, definite uniform surges of increase or decrease of velocity—in excess of 40 miles per hour per second have been measured. This rate of change, if continuing for two seconds, would represent an increase in wind velocity of 80 miles per hour. In addition to these steady accelerations, irregular increases or decreases of velocity were measured, these always taking place at relatively slower rates, but nevertheless covering a considerable change of velocity.

The practical application of this apparatus to the needs of aviation depends to a great extent on the particular purpose for which the information is desired.

*Studies of wind gustiness and temperature inversions at Lakehurst.*—The aerological office at the naval air station, Lakehurst, N. J., has carried on the study of abrupt wind shifts, wind gustiness, and temperature inversions as they relate to airship operation. Most of the records of gustiness and wind shifts have been obtained by Dines anemobiographs fitted with fast-motion record drums. Two other types of wind-velocity recorders are now in use for this purpose—one, the selsyn bridled anemometer type, the other the whirling-cup generator type which records on a sensitive recording voltmeter. Two of the Dines instruments are mounted on a base line for study of space characteristics of gusts. Severe fluctuations in wind of short duration are frequent, but sustained fluctuations of duration sufficient to affect an airship have been infrequent during the past year. Collection of records is being continued and plans have been made to increase the number of installations so as to obtain further information on the space characteristics of gusts and wind shifts.

The temperature inversion studies were conducted by means of thermographs mounted on a 175-foot mast. The study has not been completed. In the near future a new type of temperature recorder will be installed for collection of further data. Results compiled to date have yielded some interesting information pertaining to airship operation.

*Fog and fog dispersal.*—At a meeting of the subcommittee on meteorological problems held on June

26, 1930, there was discussion of the problem of fog dispersal. It appears from experiments thus far conducted that there is very little promise for the development of a commercial method of clearing away fog, although it is possible to clear away enough for certain military exigencies in cases where the question of cost is not of primary importance. The three principal methods of fog dispersal to which consideration has been given are: First, to sprinkle a quantity of hygroscopic material through the fog; second, to have a number of airplanes scatter electrified sand or other electrified particles through the fog; and third, to heat the air sufficiently to cause evaporation of the fog.

In connection with the problem of fog dispersal, there was discussion as to the desirability of conducting a theoretical study to determine whether the electrification of particles of water would lead to their coalescence.

The subcommittee has been in touch with the work of the Guggenheim Fund on the development of methods of safe flying through fog by means of instruments, and with the experiments conducted by the Army Air Corps on the use of electrified sand for fog dispersal.

*Ice formation on aircraft.*—An investigation of ice formation on airplanes in operation has been conducted by the Weather Bureau during the past two winters in cooperation with National Air Transport (Inc.). The purpose of the investigation was to determine the various conditions under which ice forms, with a view to the formulation of rules or guiding principles for the efficient forecasting of ice-forming conditions before they occur. The plan included the placing of recording aerographs on airplanes of air-mail companies in regular flight. The information obtained confirmed in general the results of the study made some time ago by the Langley Memorial Aeronautical Laboratory, indicating that the temperatures most favorable for the formation of ice are between  $0^{\circ}$  and  $-2^{\circ}$  or  $-3^{\circ}$  C., and that though ice does form in lower temperatures it is simply rime and is not heavy enough to be dangerous.

The subcommittee has kept itself informed of the work of Dr. W. C. Geer on the development of a rubber "overshoe" for the prevention of ice formation, and of the investigations conducted in the 6-inch refrigerated wind tunnel at the Langley Memorial Aeronautical Laboratory.

## PART IV

### TECHNICAL PUBLICATIONS OF THE COMMITTEE

The National Advisory Committee for Aeronautics has issued technical publications during the past year covering a wide range of subjects. There are four series of publications, namely, Technical Reports, Technical Notes, Technical Memorandums, and Aircraft Circulars.

The Technical Reports present the results of fundamental research in aeronautics carried on in different laboratories in this country, including the Langley Memorial Aeronautical Laboratory, the aerodynamical laboratory at the Washington Navy Yard, the Bureau of Standards, the Weather Bureau, Stanford University, and the Massachusetts Institute of Technology. In all cases the reports were recommended for publication by the technical subcommittees having cognizance of the investigations. During the past year 28 Technical Reports were submitted for publication.

Technical Notes present the results of short research investigations and the results of studies of specific detail problems which form parts of long investigations. The committee has issued during the past year, in mimeographed form, 30 Technical Notes.

Technical Memorandums contain translations and reproductions of important foreign aeronautical articles of a miscellaneous character. A total of 52 Technical Memorandums was issued during the past year.

Aircraft Circulars contain translations or reproductions of articles descriptive of new types of foreign aircraft. During the past year 25 Aircraft Circulars were issued.

Summaries of the 28 Technical Reports and lists of the Technical Notes, Technical Memorandums, and Aircraft Circulars follow:

#### SUMMARIES OF TECHNICAL REPORTS

The First Annual Report of the National Advisory Committee for Aeronautics for the fiscal year 1915 contained Technical Reports Nos. 1 to 7; the second annual report, Nos. 8 to 12; the third annual report, Nos. 13 to 23; the fourth annual report, Nos. 24 to 50; the fifth annual report, Nos. 51 to 82; the sixth annual report, Nos. 83 to 110; the seventh annual report, Nos. 111 to 132; the eighth annual report, Nos. 133 to 158; the ninth annual report, Nos. 159 to 185; the tenth annual report, Nos. 186 to 209; the eleventh annual report, Nos. 210 to 232; the twelfth annual report,

Nos. 233 to 256; the thirteenth annual report, Nos. 257 to 282; the fourteenth annual report, Nos. 283 to 308; the fifteenth annual report, Nos. 309 to 336; and since the preparation of the fifteenth annual report for the year 1929 the committee has authorized the publication of the following Technical Reports Nos. 337 to 364:

*Report No. 337*, entitled "The Gaseous Explosive Reaction at Constant Pressure—The Reaction Order and Reaction Rate," by F. W. Stevens, Bureau of Standards.

This investigation was carried out at the Bureau of Standards at the request of and with the financial assistance of the National Advisory Committee for Aeronautics.

1. In the case of the gaseous explosive reaction at constant pressure the data given in this report show that the statistical expression,  $r = [F]n_1 [O_2]n_2$ , derived from the order of the stoichiometric equation written for complete combustion of a fuel, is proportional to the spatial rate at which an equilibrium is established in the gaseous explosive system, and that this relation is found to hold for high reaction orders where very complex hydrocarbon fuels are involved in the transformation.

2. The above relation, since it is based solely upon the initial and final condition of the transformation, is independent of the microprocesses, whatever these may be, resulting in the final union of the initial active components in the proportions required by the reaction constant  $K$  for the temperature and pressure at which the reaction takes place.

3. The data also provide interesting confirmation of the assumption that high-order reaction processes consist of many simultaneous simpler ones, each running its course within the reaction zone "according to its own order and mechanism independently of any other reactions occurring at the same time." The probability of the correctness of this assumption is chiefly shown by the fact that the equivalent reaction order of a composite fuel may be determined from the reaction orders of its components and, further, that the velocity constant,  $k_F$ , of the fuel may also be determined from the velocity constants of those components.

4. The data given in this report all cover the "explosive limits" of the fuels investigated. Incidental

to the purpose of the investigation reported the "explosive limits" will be found to be expressed for the condition of constant pressure in the fundamental terms of concentrations (partial pressures) of fuel and oxygen. It may be seen from the results given that a fundamental relation clearly exists between explosive range and the magnitude of  $[F]_{\max}$  of the fuel.

*Report No. 338*, entitled "The Effect of Reduction Gearing on Propeller-Body Interference as Shown by Full-Scale Wind-Tunnel Tests," by Fred E. Weick, National Advisory Committee for Aeronautics.

Full-scale tests have been made in the propeller research tunnel of the National Advisory Committee for Aeronautics on a 10-foot 5-inch propeller on a geared J-5 engine and also on a similar 8-foot 11-inch propeller on a direct-drive J-5 engine. Each propeller was tested at two different pitch settings and with a large and a small fuselage. The investigation was made in such a manner that the propeller-body interference factors were isolated, and it was found that, considering this interference only, the geared propellers had an appreciable advantage in propulsive efficiency, partially due to the larger diameter of the propellers with respect to the bodies and partially because the geared propellers were located farther ahead of the engines and bodies.

*Report No. 339*, entitled "Full Scale Wind Tunnel Tests with a Series of Propellers of Different Diameters on a Single Fuselage," by Fred E. Weick, National Advisory Committee for Aeronautics.

Aerodynamic tests were made with four geometrically similar metal propellers of different diameters, on a Wright Whirlwind J-5 engine in an open-cockpit fuselage. The tests were made in the 20-foot propeller research tunnel of the National Advisory Committee for Aeronautics. The results show little difference in the characteristics of the various propellers, the only one of any importance being an increase of efficiency of the order of 1 per cent for a 5 per cent increase of diameter, within the range of the tests.

*Report No. 340*, entitled "Full Scale Wind Tunnel Tests on Several Metal Propellers Having Different Blade Forms," by Fred E. Weick, National Advisory Committee for Aeronautics.

This report gives the full-scale aerodynamic characteristics of five different aluminum-alloy propellers having four different blade forms. They were tested on an open-cockpit fuselage with a radial air-cooled engine having conventional cowling, in the 20-foot propeller research tunnel of the National Advisory Committee for Aeronautics, at Langley Field, Va. The results show that (1) the differences in propulsive efficiency due to the differences in blade form were

small; (2) the form with the thinnest airfoil sections had the highest efficiency; (3) it is advantageous as regards propulsive efficiency for a propeller operating in front of a body, such as a radial engine, to have its pitch reduced toward the hub.

*Report No. 341*, entitled "The Design and Development of an Automatic Injection Valve with an Annular Orifice of Varying Area," by William F. Joachim, Chester W. Hicks, and Hampton H. Foster, National Advisory Committee for Aeronautics.

The injection valve described in this report was designed and developed at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics in connection with a general research on aircraft oil engines. The purpose of this investigation was to provide an automatic injection valve of simple construction which would produce a finely atomized oil spray of broad cone angle and would fulfill the requirements of fuel injection in aircraft oil engines. The injection valve designed has only six parts—that is, 2 concentric nozzle tubes flared at one end, 2 body parts, and 2 nuts. The nozzle tubes are provided with seats at the flared ends to form an annular orifice which automatically varies in area with the injection pressure. Adjustment of the nuts determines the valve-opening pressure. The fuel passage to the orifice is provided by the clearance space between the nozzle tubes. When sufficient oil pressure is developed by the fuel pump, the flared ends of the nozzle tubes move apart slightly and the oil passes through the annular orifice, producing a broad conical spray. The nozzle tubes are so constructed as to cause the cylinder gases to heat them approximately 500° F., which preheats the oil and tends to reduce the ignition lag.

The results of tests made with the N. A. C. A. spray photography equipment on this injection valve indicate the effect of several factors on spray penetration. For a duration of injection 0.003 second, and a valve-opening pressure of 2,500 pounds per square inch, a change of injection pressure from 6,000 to 10,000 pounds per square inch increased the penetration 25 per cent. For a constant speed and fuel quantity per cycle a change of valve-opening pressure from 2,000 to 5,000 pounds per square inch, which caused a corresponding change in maximum injection pressure from 6,700 to 10,500 pounds per square inch, increased the penetration 5 per cent. A change of spray-chamber air density corresponding to a change of compression ratio from 11.2 to 15.3 decreased the spray penetration 8 per cent. Curves are presented showing these effects together with the effect of engine-operating temperature on the valve-opening pressure.

Analysis and engine tests indicate that the fuel spray from this type of injection valve has character-



istics which reduce the time lag of autoignition and promote efficient combustion in high-speed oil engines.

*Report No. 342*, entitled "Effect of Turbulence in Wind Tunnel Measurements," by H. L. Dryden and A. M. Kuethe, Bureau of Standards.

This investigation was carried out at the Bureau of Standards at the request of and with the financial assistance of the National Advisory Committee for Aeronautics. The paper gives some quantitative measurements of wind-tunnel turbulence and its effect on the air resistance of spheres and airship models, these measurements having been made possible by the hot-wire anemometer and related apparatus developed at the Bureau of Standards. The apparatus in its original form was described in Technical Report No. 320 and some modifications are presented in an appendix to the present paper.

One important result of the present work is a curve by means of which measurements of the air resistance of spheres can be interpreted to give the turbulence quantitatively. Another is the definite proof that the discrepancies in the results on the N. P. L. standard airship models are due mainly to differences in the turbulence of the wind tunnels in which the tests were made.

An attempt is made to interpret the observed results in terms of the boundary-layer theory, and for this purpose a brief account is given of the physical bases of this theory and of conceptions that have been obtained by analogy with the laws of flow in pipes.

*Report No. 343*, entitled "Effect of Variation of Chord and Span of Ailerons on Rolling and Yawing Moments at Several Angles of Pitch," by R. H. Heald, D. H. Strother, and B. H. Monish, Bureau of Standards.

This report presents the results of an extension to higher angles of attack of the investigation described in Technical Report No. 298, of the rolling and yawing moments due to ailerons of various chords and spans on two airfoils having the Clark Y and U. S. A. 27 wing sections.

The measurements were made at various angles of pitch but at zero angle of roll and yaw, the wing chord being set at an angle of  $+4^\circ$  to the fuselage axis. In the case of the Clark Y airfoil the measurements have been extended to a pitch angle of  $40^\circ$ , using ailerons of span equal to 67 per cent of the wing semi-span and chord equal to 20 and 30 per cent of the wing chord. It is planned later to extend the investigation to hinge moments of the ailerons for the conditions covered in the rolling and yawing moment tests.

The work was conducted in the 10-foot wind tunnel of the Bureau of Standards on wing models of 60-inch span and 10-inch chord.

*Report No. 344*, entitled "The Design of Plywood Webs for Airplane Wing Beams," by George W. Trayer, Forest Products Laboratory.

This report of the Forest Products Laboratory deals with the design of plywood webs for wooden box beams to obtain maximum strength per unit weight. A method of arriving at the most efficient and economical web thickness, and hence the most suitable unit shear stress, is presented, and working stresses in shear for various types of webs and species of plywood are given. The questions of diaphragm spacing and required glue area between the webs and the flange are also discussed.

*Report No. 345*, entitled "The Design of Airplane Wing Ribs," by J. A. Newlin and George W. Trayer, Forest Products Laboratory.

The purpose of the investigation described in this report was to obtain information for use in the design of truss and plywood forms, particularly with reference to wing ribs. Tests were made on many designs of wing ribs, comparing different types in various sizes. Many tests were also made on parallel-chord specimens of truss and plywood forms in place of the actual ribs and on parts of wing ribs, such as truss diagonals and sections of cap strips.

It was found that for ribs of any size or proportions, when they were designed to obtain a well-balanced construction and were carefully manufactured, distinct types are of various efficiencies; the efficiency is based on the strength per unit of weight. With ideal construction the truss comes first; second, a lightened and reinforced plywood type; third, a full plywood web type with stiffeners; fourth, a plywood web with lightening holes and no reinforcing; and fifth, a full web with no stiffeners. If a type falls out of this order, the probable reason is either that it is poorly designed or that it was designed with some special consideration for manufacturing details and is, therefore, not so strong for its weight as it can be made.

Each type has its place in airplane design because manufacturing difficulties set up practical limits for the various types. For example, shallow trusses can not be manufactured and assembled without great difficulty. Neither can a reinforced plywood truss be substituted for a full plywood type when to obtain maximum efficiency an excessively thin plywood must be used.

In all types of ribs the heavier are the stronger per unit of weight. Reductions in the weight of wing ribs are accompanied even in efficient designs by a much greater proportional reduction in strength.

Obtaining maximum efficiency in truss designs would require all diagonals to be of cruciform cross section and all members to be proportioned according to their individual stresses.



Members with thin, outstanding flanges and with little torsional rigidity, especially U sections, fail by twisting, at times carrying only 50 per cent of the calculated compression load. Slight modifications in cross section without change in area increase the torsional rigidity sufficiently to overcome this twisting.

In resistance to both end loads and bending, U and T sections built up of wood and plywood in combination are inefficient as compared with sections having the grain of the wood all parallel to the axis of the piece.

Compression diagonals are more suitable in the panels adjacent to the spars than tension diagonals, since tension diagonals have been found more difficult to hold at the joint than compression diagonals.

Bending stresses in plywood types can be calculated with a fair degree of accuracy provided that the plywood is of sufficient thickness or is so braced as to prevent buckling and the rib is so braced as to prevent bending of the caps out of the plane of the rib. Form factor must be taken into account, and in calculating the moment of inertia only that part of the plywood having grain parallel to the axis of the rib should be included.

No tests were made from which the required vertical rigidity of the webs can be determined absolutely, but approximately it may be said that any unit of length, including its proportional part of the stiffeners, should be able to carry, as a pin-end column, two-thirds of the load that will come upon this unit of length when the rib is loaded to failure.

Plywood webs with a balsa core proved very satisfactory from a construction standpoint and in full webs were found to be strong per unit of weight in comparison with other plywoods. When lightening holes were added, however, the strength dropped very rapidly because of the ease with which the face plies tore the balsa core apart around the holes at the least tendency to buckle. Even shrinkage and swelling stresses may cause rupture of the balsa core at the edges of the lightening holes.

In general, vertical face grain in plywood webs gives consistently greater strength when a full web is used, but longitudinal face grain is better when a web with lightening holes and stiffeners is used.

Webs of single-ply spruce, in comparison with 3-ply poplar plywood webs of the same total thickness, proved stronger than the plywood when lightening holes were present and somewhat weaker when no holes were present.

Two-piece cap strips in most designs are preferable to single-piece cap strips.

Wide diagonals and web members are subject to large indeterminate secondary stresses, which often start failures. A similar concentration of stress occurs around lightening holes, causing buckling.

The coefficient of fixity for diagonal members under compression appears to be about one and one-half in a plane at right angles to the plane of the rib.

Maximum efficiency appears to be obtained with a ratio of spar spacing to height of about 6, except for full plywood types without stiffeners, for which the ratio appears to be about 11.

Double compression members with a spacer block at the center were found to be about one-half as strong as the same members brought together and glued throughout their length when the length is such as to throw both in the Euler column class.

Small stiffeners glued near the edges of lightening holes were found very effective in reducing buckling; the small resulting percentage of increase in weight will often be accompanied by several times that percentage increase in strength. Reinforcing around lightening holes to avoid buckling should be equally satisfactory in metal construction.

The appendix of this report contains other comments on various designs and a description of characteristic failures.

*Report No. 346*, entitled "Water Pressure Distribution on a Flying Boat Hull," by F. L. Thompson, National Advisory Committee for Aeronautics.

The investigation described in this report was conducted by the National Advisory Committee for Aeronautics at the request of the Bureau of Aeronautics, Navy Department. This is the third of a series of investigations of the water pressures on seaplane floats and hulls, and completes the present program. It consists of determining the water pressures and accelerations on a Curtiss *H-16* flying boat during landing and taxiing maneuvers in smooth and rough water.

The results show that the greatest water pressures occur near the keel at the main step, where the maximum pressure is approximately 15 pounds per square inch. From this point maximum pressures decrease in magnitude toward the bow and chine. Pressures of approximately 11 pounds per square inch were experienced at the keel slightly forward of the middle of the forebody when taking off in rough water. The area of the forebody subjected to considerable pressure is roughly a triangle having its base at the step and its apex on the keel at the load water line forward. On the bottom between steps a maximum pressure of 8 pounds per square inch is nearly uniform. A vertical acceleration of 4.7 *g* is the greatest value encountered in landings and is considerably greater than any other value recorded. It was found that 3 *g* is approximately the maximum to be expected in take-offs in rough water and that this value was exceeded during only a few landings. A longitudinal acceleration of 0.9 *g* was once attained in a landing in rough water and 0.7 *g* is not unusual for take-offs in rough water.

The maximum lateral acceleration attained in cross-wind landings is approximately 0.5 *g*. The results show that the landing loads were usually borne by an area near the main step and that rough water may cause large loads to be applied near the middle of the forebody.

*Report No. 347*, entitled "A Method of Calculating the Ultimate Strength of Continuous Beams," by J. A. Newlin and George W. Trayer, Forest Products Laboratory.

In the design of continuous beams subjected to transverse load only it has been common practice to estimate maximum loads by substituting the numerical value of the modulus of rupture, as obtained in bending tests, in the usual equation of three moments. Further, for combined axial and transverse loading, two methods of calculation have been used. The more common one is the application of the generalized equation of three moments, while the other is an extension of the ordinary equation of three moments to allow for the moments introduced by the direct tension or compression load. In the second method the deflection in the span at the point of maximum moment is calculated, neglecting the effect of axial load, and the product of the axial load and this deflection is added to the moment determined by the ordinary equation of three moments.

Both of these methods are used to calculate maximum loads, although neither is properly applicable beyond the elastic limit. The purpose of the study described in this report was to investigate conditions after the elastic limit has been passed. As a result of the study a method of calculation which is applicable to maximum-load conditions has been developed. The method is simpler than the methods now in use and applies properly to conditions where the present methods fail to apply.

The experimental work was conducted at the Forest Products Laboratory in cooperation with the Bureau of Aeronautics, Navy Department, and the results submitted to the National Advisory Committee for Aeronautics for publication. Over 300 continuous beams were tested under transverse load and under combined axial and transverse load. Loads obtained in test for beams of rectangular section were as much as 50 per cent in excess of loads calculated by the usual methods, with the average about 25 per cent. For I beams the average increase was about 40 per cent. Fortunately, the error in the usual calculation is on the side of safety, but it is too great to be neglected in good design.

*Report No. 348*, entitled "Strength of Welded Joints in Tubular Members for Aircraft," by H. L. Whittemore and W. C. Brueggeman, Bureau of Standards.

This investigation was made by the Bureau of Standards in cooperation with the National Advisory

Committee for Aeronautics for the Aeronautics Branch of the Department of Commerce. The object of the investigation is to make available to the aircraft industry authoritative information on the strength, weight, and cost of a number of types of welded joints. This information will also assist the Aeronautics Branch in its work of licensing airplanes by providing data from which the strength of a given joint may be estimated. As very little material on the strength of aircraft welds has been published, it is believed that such tests made by a disinterested governmental laboratory should be of considerable value to the aircraft industry.

Following the program prepared from information supplied by manufacturers, 40 joints were welded under procedure specifications and tested to determine their strength. The weight and time required to fabricate were also measured for each joint.

*Report No. 349*, entitled "A Proof of the Theorem Regarding the Distribution of Lift Over the Span, for Minimum Induced Drag," by W. F. Durand, Stanford University.

The proof of the theorem that the elliptical distribution of lift over the span is that which will give rise to the minimum induced drag has been given in a variety of ways, generally speaking too difficult to be readily followed by the graduate of the average good technical school of the present day. In the form of proof set forth in this report, an effort is made to bring the matter more readily within the grasp of this class of readers. The steps in the proof, briefly outlined, are as follows:

1. Given a basic distribution of lift across the span denoted by (*a*) with a second supplementary distribution denoted by (1). Then it is shown that the induced drag of lift (*a*) in the downwash due to lift (1) and the induced drag of lift (1) in the downwash due to lift (*a*) are equal, and that the total effect of the small distribution (1) on the induced drag will be measured by twice either of these small quantities.

2. Next two small changes are assumed in a basic distribution (*a*). These are represented by (1) and (2), and are further assumed to be equal in amount and opposite in algebraic sign, thus leaving the original lift unchanged in amount, but changed in distribution. Under these conditions it is then shown that in order for the distribution (*a*) to be that for minimum induced drag, the change in induced drag due to this small change in distribution must be zero.

3. It is next shown that for any pair of small changes such as (1) and (2) the only value of the basic downwash which will meet the condition of step (2) is downwash constant across the span.

4. It is known mathematically that the elliptical distribution across the span is that which gives a constant value of the downwash and hence as a result of

(1), (2), (3), this must be the distribution which will give the minimum value of the induced drag.

*Report No. 350*, entitled "Working Charts for the Selection of Aluminum Alloy Propellers of a Standard Form to Operate with Various Aircraft Engines and Bodies," by Fred E. Weick, National Advisory Committee for Aeronautics.

Working charts are given for the convenient selection of aluminum alloy propellers of a standard form to operate in connection with six different engine-fuselage combinations. The charts have been prepared from full-scale test data obtained in the 20-foot propeller research tunnel of the National Advisory Committee for Aeronautics. An example is also given showing the use of the charts.

*Report No. 351*, entitled "Full Scale Wind Tunnel Tests of a Propeller with the Diameter Changed by Cutting Off the Blade Tips," by Donald H. Wood, National Advisory Committee for Aeronautics.

Tests were conducted in order to determine how the characteristics of a propeller are affected by cutting off the tips. The diameter of a standard 10-foot metal propeller was changed successively to 9 feet 6 inches, 9 feet 0 inches, 8 feet 6 inches, and 8 feet 0 inches. Each propeller thus formed was tested at four pitch settings in the propeller-research tunnel of the National Advisory Committee for Aeronautics with an open-cockpit fuselage and a *D-12* engine.

A small loss in propulsive efficiency is indicated. Examples are given showing the application of the results to practical problems.

*Report No. 352*, entitled "Large-Scale Aerodynamic Characteristics of Airfoils as Tested in the Variable Density Wind Tunnel," by Eastman N. Jacobs and Raymond F. Anderson, National Advisory Committee for Aeronautics.

In order to give the large-scale characteristics of a variety of airfoils in a form which will be of maximum value, both for airplane design and for the study of airfoil characteristics, a collection has been made of the results of airfoil tests made at full-scale values of the Reynolds Number in the variable-density wind tunnel of the National Advisory Committee for Aeronautics. They have been corrected for tunnel-wall interference and are presented not only in the conventional form but also in a form which facilitates the comparison of airfoils and from which corrections may be easily made to any aspect ratio.

An example showing the method of correcting the results to a desired aspect ratio has been given for the convenience of designers. In addition, the data have been analyzed with a view to finding the variation of the aerodynamic characteristics of airfoils with their thickness and camber.

*Report No. 353*, entitled "Airfoil Pressure Distribution Investigation in the Variable-Density Wind Tunnel," by Eastman N. Jacobs, John Stack, and Robert M. Pinkerton, National Advisory Committee for Aeronautics.

With a view to extending the knowledge of the aerodynamics of lifting surfaces, the distribution of pressure over one section each of six airfoils has been measured in the variable-density wind tunnel of the National Advisory Committee for Aeronautics. The following airfoils were investigated: N. A. C. A. 85-J, N. A. C. A. 84-J, N. A. C. A. 84, N. A. C. A. M-6, Clark Y, and R. A. F. 30.

Pressure-distribution diagrams, as well as the integrated characteristics of the airfoils, are given for both a high and a low dynamic scale Reynolds Number or  $Vl/\mu$ , for comparison with flight and other wind-tunnel tests, respectively. It is concluded that the scale effect is very important only at angles of attack near the burble. The distribution of pressure over an airfoil having a Joukowski section is compared with the theoretically derived distribution. A further study of the distribution of pressure over all of the airfoils resulted in the development of an approximate method of predicting the pressure distribution along the chord of any normal airfoil for all attitudes within the working range if the distribution at one attitude is known.

*Report No. 354*, entitled "Aircraft Woods: Their Properties, Selection, and Characteristics," by L. J. Markwardt, Forest Products Laboratory.

Wood has been one of the pioneer materials in aircraft construction. Its salient qualities—a high ratio of strength to weight; lightness, affording readily the size of member required to resist twisting and lateral buckling; ease of manufacture; facility of repair without specialized equipment and without highly skilled labor; and adaptability to small-scale production—have always permitted it to serve usefully. Although a lack of uniformity in the quality of wood is perhaps the most important factor now militating against its continued use in present-day quantity production, the existing detailed knowledge of the properties and the causes of variation in them, determined at the Forest Products Laboratory and submitted to the National Advisory Committee for Aeronautics for publication, makes it possible to select aircraft material with assurance and places design on a reliable basis.

Strength values of various woods for aircraft design for a 15 per cent moisture condition of material and a 3-second duration of stress are presented, and also a discussion of the various factors affecting the values. The toughness-test method of selecting wood is discussed, and a table of acceptance values for several species is given.

This report presents, further, information on the properties of various other native species of wood compared with spruce, and discusses the characteristics of a considerable number of them from the standpoint of their possible application in aircraft manufacture to supplement the woods that are now most commonly used.

*Report No. 355*, entitled "Comparative Flight Performance with an N. A. C. A. Roots Supercharger and a Turbocentrifugal Supercharger," by Oscar W. Schey and Alfred W. Young, National Advisory Committee for Aeronautics.

As there are now several types of superchargers in service, information on the comparative performance obtained with each type of supercharger would be of value in the selection of a supercharger to meet definite service requirements. As a part of the program to obtain this information, the National Advisory Committee for Aeronautics conducted tests, using a modified DH-4M2 airplane with a turbocentrifugal and with a Roots type supercharger. The rate of climb and the high speed in level flight of the airplane were obtained for each supercharger from sea level to the ceiling. The unsupercharged performance with each supercharger mounted in place was also determined.

The results of these tests show that the ceiling and rate of climb obtained were nearly the same for each supercharger, but that the high speed obtained with the turbocentrifugal was better than that obtained with the Roots. The high-speed performance at 21,000 feet was 122 and 142 miles per hour for the Roots and turbocentrifugal, respectively.

*Report No. 356*, entitled "Strength of Rectangular Flat Plates Under Edge Compression," by Louis Schuman and Goldie Back, Bureau of Standards.

Flat rectangular plates of duralumin, stainless iron, Monel metal, and nickel were tested under loads applied at two opposite edges and acting in the plane of the plate. The edges parallel to the direction of loading were supported in V grooves. The plates were all 24 inches long and varied in width from 4 to 24 inches by steps of 4 inches, and in thickness from 0.015 to 0.095 inch by steps of approximately 0.015 inch. There were also a few 1, 2, 3, and 6-inch wide specimens. The loads were applied in the testing machine at the center of a bar which rested along the top of the plate. Load was applied until the plate failed to take any more load.

The tests show that the loads carried by the plates generally reached a maximum for the 8 or 12-inch width and that there was relatively small drop in load for the greater widths. This is explained by the fact that when the plate buckles, since the greatest deflection occurs at the center, its vertical chords will

shorten more there than at the ends. In consequence there will be less load on the plate at the center and more toward the ends where it is better supported to resist bending and can continue to take load after buckling has occurred. In this way the load carried by plates of a given thickness would tend to be constant for all plates wider than that at which the maximum load is reached.

Deflection and set measurements perpendicular to the plane of the plate were taken and the form of the buckle determined. The number of buckles was found to correspond in general to that predicted by the theory of buckling of a plate uniformly loaded at two opposite edges and simply supported at the edges.

The tests were made by the Bureau of Standards in cooperation with the Bureau of Aeronautics of the Navy Department, and the results submitted to the National Advisory Committee for Aeronautics for publication. The materials chosen were those suitable for aircraft construction. The data obtained will be of use in the design of floats, pontoons, wings, etc., of aircraft when the plating is subjected to pressure against the edges. It is desired to make this construction as light as possible, yet strong enough to take the required loads without permanent deformation.

*Report No. 357*, entitled "Aircraft Accidents—Method of Analysis," by committee on aircraft accidents, National Advisory Committee for Aeronautics.

This report is a revision and expansion of the report prepared by the special committee on the nomenclature, subdivision, and classification of aircraft accidents, which was issued as Technical Report No. 308 of the National Advisory Committee for Aeronautics. The revised report includes the chart for the analysis of aircraft accidents, combining consideration of the immediate causes, underlying causes, and results of accidents, as prepared by the special committee, with a number of the definitions clarified; a brief statement of the organization and work of the special committee and of the committee on aircraft accidents; and statistical tables giving a comparison of the types of accidents and causes of accidents in the military services on the one hand and in civil aviation on the other, together with explanations of some of the important differences noted in these tables.

*Report No. 358*, entitled "Temperature Coefficient of the Modulus of Rigidity of Aircraft Instrument Diaphragm and Spring Materials," by W. G. Brombacher and E. R. Melton, Bureau of Standards.

Experimental data are presented on the variation of the modulus of rigidity in the temperature range  $-20^{\circ}$  to  $+50^{\circ}$  C. of a number of metals which are of possible use for elastic elements for aircraft and other instruments. The method of the torsional pendulum was used to determine the modulus of rigidity and its

temperature coefficient for aluminum, duralumin, Monel metal, brass, phosphor bronze, coin silver, nickel silver, three high-carbon steels, and three alloy steels. The temperature coefficient  $m$  is defined by the relation—

$$m = \frac{1}{G_0} \frac{dG}{dT}$$

in which  $G$  and  $G_0$  are the moduli of rigidity at the temperatures  $T^\circ \text{C.}$  and  $0^\circ \text{C.}$  The differential  $dG/dT$  was found to be a constant except for two metals. The effect of heat treatment on  $m$  was determined for a number of the materials. It was observed that tensile stress affected the values of the modulus by amounts of 1 per cent or less.

*Report No. 359*, entitled "An Investigation of the Effectiveness of Ignition Sparks," by Melville F. Peters, Wayne L. Summerville, and Merlin Davis, Bureau of Standards.

The effectiveness of ignition sparks was determined by measuring the volume (or mass) of hydrogen and of oxygen which combines at low pressures. The sparks were generated by a magneto and an ignition spark coil. It was found that with constant energy the amount of reaction increases as the capacitance component of the spark increases. The use of a series spark gap may decrease or increase the amount of reaction, the effect depending upon the amount and the distribution of capacitance in the circuit. So far as the work has progressed, it has been found that sparks reported by other investigators as being most efficient for igniting lean mixtures cause the largest amount of reaction. Differences between the amount of reaction with a magneto spark and an ignition spark coil were noted. The method appears to offer a means of determining the most efficient spark generator for internal-combustion engines as well as determining a relation between the character of spark, energy, and effectiveness in igniting inflammable mixtures.

*Report No. 360*, entitled "Pressure Distribution Over a Symmetrical Airfoil Section with Trailing Edge Flap," by Eastman N. Jacobs and Robert M. Pinkerton, National Advisory Committee for Aeronautics.

Measurements were made in the variable-density wind tunnel of the National Advisory Committee for Aeronautics to determine the distribution of pressure over one section of an R. A. F. 30 (symmetrical) airfoil with trailing edge flaps. In order to study the effect of scale, measurements were made with air densities of approximately 1 and 20 atmospheres.

Isometric diagrams of pressure distribution are given to show the effect of change in incidence, flap displacement, and scale upon the distribution. Plots of normal force coefficient versus angle of attack for different flap displacements are given to show the

effect of a displaced flap. Finally, plots are given of both the experimental and theoretical characteristic coefficients versus flap angle in order to provide a comparison with the theory. It is concluded that for small flap displacements the agreement for the pitching and hinge moments is such that it warrants the use of the theoretical parameters. However, the agreement for the lift is not as good, particularly for the smaller flaps. In an appendix an example is given of the calculation of the load and moments on an airfoil with hinged flap from these parameters.

*Report No. 361*, entitled "Experimental Determination of Jet Boundary Corrections for Airfoil Tests in Four Open Wind-Tunnel Jets of Different Shapes," by Montgomery Knight and Thomas A. Harris, National Advisory Committee for Aeronautics

This experimental investigation was conducted primarily for the purpose of obtaining a method of correcting to free-air conditions the results of airfoil force tests in four open wind-tunnel jets of different shapes. Tests were also made to determine whether the jet boundaries had any appreciable effect on the pitching moments of a complete airplane model. The investigation was conducted in the atmospheric wind tunnel of the Langley Memorial Aeronautical Laboratory.

The method of obtaining the airfoil corrections utilized the results of force tests made in each jet on three similar monoplane airfoil set-ups of different sizes. The data from the tests in one of the jets which was circular were extrapolated to the condition of infinite air space, and the results were found to agree with those obtained by means of Prandtl's theoretical method of correction. On this basis corrections were then obtained for all the other airfoil tests.

Satisfactory corrections for the effect of the boundaries of the various jets were obtained for all the airfoils tested, the span of the largest being 0.75 of the jet width. The corrections for angle of attack were, in general, larger than those for drag. The boundaries had no appreciable effect on the pitching moments of either the airfoils or the complete airplane model. Increasing the turbulence appeared to increase the minimum drag and maximum lift and to decrease the pitching moment.

*Report No. 362*, entitled "An Extended Theory of Thin Airfoils and its Application to the Biplane Problem," by Clark B. Millikan, California Institute of Technology.

The present paper gives a new treatment, due essentially to Von Karman, of the problem of the thin airfoil. The standard formulæ for the angle of zero lift and zero moment are first developed and the analysis is then extended to give the effect of disturbing or interference velocities, corresponding to an arbitrary potential flow, which are superimposed on a

normal rectilinear flow over the airfoil. An approximate method is presented for obtaining the velocities induced by a 2-dimensional airfoil at a point some distance away. In certain cases this method has considerable advantage over the simple "lifting line" procedure usually adopted. The interference effects for a 2-dimensional biplane are considered in the light of the previous analysis. The results of the earlier sections are then applied to the general problem of the interference effects for a 3-dimensional biplane, and formulæ and charts are given which permit the characteristics of the individual wings of an arbitrary biplane without sweepback or dihedral to be calculated. In the final section the conclusions drawn from the application of the theory to a considerable number of special cases are discussed, and curves are given illustrating certain of these conclusions and serving as examples to indicate the nature of the agreement between the theory and experiment.

*Report No. 303*, entitled "Pressure Fluctuations in a Common-Rail Fuel-Injection System," by A. M. Rothrock, National Advisory Committee for Aeronautics.

The tests described in this report were conducted at the Langley Memorial Aeronautical Laboratory to determine experimentally the instantaneous pressures at the discharge orifice of a common-rail fuel-injection system in which the timing valve and cut-off valve were at some distance from the automatic fuel-injection valve, and also to determine the methods by which the pressure fluctuations could be controlled.

The instantaneous pressures at the discharge orifice of a common-rail fuel-injection system were determined by analyzing the stem-lift records of an automatic-injection valve. The fuel injection was obtained by releasing fuel from a reservoir under high pressure by means of a cam-operated timing valve. The period of injection was controlled by the opening of a cam-operated by-pass valve which reduced the fuel pressure between the timing valve and the injection valve. An injection system of this type assures the same rate of fuel discharge regardless of engine speed. The results show that pressure wave phenomena occur between the high-pressure reservoir and the discharge orifice, but that these pressure waves can be controlled so as to be advantageous to the injection of the fuel. The results also give data applicable to the design of such an injection system for a high-speed compression-ignition engine.

*Report No. 364*, entitled "The Pressure Distribution Over the Wings and Tail Surfaces of a PW-9 Pursuit Airplane in Flight," by Richard V. Rhode, National Advisory Committee for Aeronautics.

The investigation described in this report was conducted at the Langley Memorial Aeronautical Laboratory, by the National Advisory Committee for

Aeronautics at the request of the Army Air Corps, to determine (1) the magnitude and distribution of aerodynamic loads over the wings and tail surfaces of a pursuit-type airplane in the maneuvers likely to impose critical loads on the various subassemblies of the airplane structure; (2) to study the phenomenon of the movement of the center of pressure and the variation of the normal force coefficient in accelerated flight; and (3) to measure the normal accelerations at the center of gravity, wing-tip, and tail, in order to determine the nature of the inertia forces acting simultaneously with the critical aerodynamic loads.

The investigation comprised simultaneous measurements of pressure at 120 stations distributed over the right upper wing, left lower wing, right horizontal tail surfaces, and complete vertical surfaces in one installation and the same number of points distributed over those portions of the wings in the slipstream and the left horizontal tail surfaces in another installation, during a series of level flight runs, pull-ups, rolls, spins, dives, and inverted-flight maneuvers. Measured also were the accelerations mentioned above, angular velocities, air speed, and control positions simultaneously with the pressures.

The results obtained throw light on a number of important questions involving structural design. Some of the more interesting results have been discussed in some detail, but in general the report is for the purpose of making this collection of airplane-load data obtained in flight available to those interested in airplane structure.

#### LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

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| No.  |  |
| 320. | The Drag and Interference of a Nacelle in the Presence of a Wing. By Eastman N. Jacobs.  |
| 321. | The Impact on Seaplane Floats During Landing. By Th. von Karman.   |
| 322. | The Effect of the Wings of Single Engine Airplanes on Propulsive Efficiency as Shown by Full-Scale Wind-Tunnel Tests. By Fred E. Weick and Donald H. Wood.   |
| 323. | Wind-Tunnel Tests on Airfoil Boundary Layer Control Using a Backward Opening Slot. By Montgomery Knight and Millard J. Bamber.   |
| 324. | Wind-Tunnel Tests on an Airfoil Equipped with a Split Flap and a Slot. By Millard J. Bamber.   |
| 325. | Wind-Tunnel Pressure Distribution Tests on a Series of Biplane Wing Models. Part II: Effects of Changes in Decalage, Dihedral, Sweepback, and Overhang. By Montgomery Knight and Richard W. Noyes. |
| 326. | Wind-Tunnel Pressure Distribution Tests on an Airfoil with Trailing Edge Flap. By Carl J. Wenzinger and Oscar Loeser, Jr.  |

327. Some Studies on the Aerodynamic Effect of the Gap between Airplane Wings and Fuselages. By Shatswell Ober.
328. The Effect of Fuel Consumption on Cylinder Temperatures and Performance of a Cowled Wright J-5 Engine. By Oscar W. Schey.
329. Some Effects of Air Flow on the Penetration and Distribution of Oil Sprays. By A. M. Rothrock and E. G. Beardsley.
330. Wind-Tunnel Pressure Distribution Tests on a Series of Biplane Wing Models. Part III: Effects of Changes in Various Combinations of Stagger, Gap, Sweepback, and Decalage. By Montgomery Knight and Richard W. Noyes.
331. Rate of Heat Transfer from Finned Metal Surfaces. (Progress Report on Investigations at Aeronautical Engineering Department, Massachusetts Institute of Technology.) By C. Fayette Taylor and A. Rehbock.
332. Injection Lags in a Common-Rail Fuel Injection System. By A. M. Rothrock.
333. Test of an Adjustable Pitch Model Propeller at Four Blade Settings. By E. P. Lesley.
334. Comparative Performance Obtained with XF7C-1 Airplane Using Several Different Engine Cowlings. By Oscar W. Schey, Ernest Johnson, and Melvin N. Gough.
335. The Structure and Properties of Parachute Cloths. By H. J. McNicholas and A. F. Hedrick.
336. The Effect of Wing Tip Floating Ailerons on the Autorotation of a Monoplane Wing Model. By Montgomery Knight and Carl J. Wenzinger.
337. Pressure Distribution on the Tail Surfaces on a PW-9 Pursuit Airplane in Flight. By Richard V. Rhode.
338. Some Effects of Air and Fuel Oil Temperatures on Spray Penetration and Dispersion. By A. G. Gelalles.
339. Refrigerated Wind Tunnel Tests on Surface Coatings for Preventing Ice Formation. By Montgomery Knight and William C. Clay.
340. Full Scale Drag Tests on Various Parts of Fairchild (FC-2W2) Cabin Monoplane. By William H. Herrnstein, Jr.
341. Calibration and Lag of a Friez Type Cup Anemometer. By Robert M. Pinkerton.
342. Identification of Aircraft Tubing by Rockwell Test. By Horace Knerr.
343. Strength in Shear of Thin Curved Sheets of Alclad. By George Michael Smith.
344. Performance of a High-Speed Compression-Ignition Engine Using Multiple Orifice Fuel Injection Nozzles. By J. A. Spanogle and H. H. Foster.
345. The Prevention of the Ice Hazard on Airplanes. By William O. Geer and Merit Scott.
346. Span Load Distribution on Two Monoplane Wing Models as Affected by Twist and Sweepback. By Montgomery Knight and Richard W. Noyes.
347. The Pressure Distribution Over a Douglas Wing Tip on a Biplane in Flight. By Richard V. Rhode and Eugene E. Lundquist.
348. Alterations and Tests of the "Farnboro" Engine Indicator. By John H. Collins, Jr.
349. An Investigation of Airplane Landing Speeds. By Kenneth F. Ridley.

#### LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

- | No.  |  |
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| 533. | Handley Page Metal Construction. From Flight, May 9, 1929.   |
| 534. | Experiments with a Wing Model from Which the Boundary is Removed by Suction. By Oskar Schrenk. Translation from Luftfahrtforschung, June 11, 1928.   |
| 535. | Information Obtained from Airplane Flight Tests in the Year 1927-28. By W. Hübner. Translation from Zeitschrift für Flugtechnik und Motorluftschiffahrt, April 29, 1929.   |
| 536. | Fire Prevention on Airplanes. Part I. By J. Sabatier. Translation from Bulletin Technique No. 56, of the Service Technique et Industriel de L'Aeronautique, January, 1929.   |
| 537. | Fire Prevention on Airplanes. Part II. By J. Sabatier. Translation from Bulletin Technique No. 56, of the Service Technique et Industriel de L'Aeronautique, January, 1929.  |
| 538. | Cantilever Wings for Modern Aircraft. Some Aspects of Cantilever Wing Construction with Special Reference to Weight and Torsional Stiffness. By H. J. Stieger. From Aircraft Engineering, August, 1929.              |
| 539. | Unsymmetrical Forces in an Airplane Cell. By R. Vogt. Translation from Zeitschrift für Flugtechnik und Motorluftschiffahrt, June 14, 1929.   |
| 540. | Mathematical and Experimental Investigation of Heat Control and Power Increase in Air-Cooled Aircraft Engines. By F. Gossiau. Translation from Zeitschrift für Flugtechnik und Motorluftschiffahrt, October 7, 1928. |
| 541. | Technical Details in the Structural Development of Rohrbach Seaplanes. By Gotthold Mathias and Adolf Holzapfel. Translation from Zeitschrift für Flugtechnik und Motorluftschiffahrt, July 15, 1929.                 |



542. Contribution to the Aileron Theory. By A. Betz and E. Petersohn. Translation from *Zeitschrift für angewandte Mathematik und Mechanik*, August, 1928, Vol. VIII.
543. Calculation of the Pressures on Aircraft Engine Bearings. By O. Steigenberger. Translation from *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, March 14, 1929.
544. Airplane Drag. By Carl Töpfer. Translation from *Die Luftwacht*, September, 1929.
545. The Balance of Moments and the Static Longitudinal Stability of Airplanes. By Horst Muller. Translation from *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, January 28, 1929.
546. Structural Details of the Giant Dornier Seaplane *Do. X*. By Corrado Gustosa. Translation from *Rivista Aeronautica*, October, 1929.
547. Contribution to the Study of Normal Burning in Gaseous Carbureted Mixtures. By M. R. Duchene. Part I. Translation from *Service Technique et Industriel de L'Aeronautique*, Bulletin Technique No. 54, December, 1928.
548. Contribution to the Study of Normal Burning in Gaseous Carbureted Mixtures. By M. R. Duchene. Part II. Translation from *Service Technique et Industriel de L'Aeronautique*, Bulletin Technique No. 54, December, 1928.
549. Coefficients of Flow of Standard Nozzles. By H. Mueller and H. Peters. Translation from *Zeitschrift des Vereines deutscher Ingenieure*, No. 27, July 6, 1929.
550. Combating Airplane Fires. By Henri Brunat. Translation from a booklet published by the *Comite Francais de Propagande Aeronautique*, Paris.
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553. Experimental Investigations Concerning the Limits of Detonation in Gaseous Mixtures. By Rudolf Wendlandt. Part I. Translation from *Zeitschrift für Physikalische Chemie* 110, 637. 1924.
554. Experimental Investigations Concerning the Limits of Detonation in Gaseous Mixtures. By Rudolf Wendlandt. Part II. Translation from *Zeitschrift für Physikalische Chemie* 116, 227, 1925.
555. The Boundary Layer as a Means of Controlling the Flow of Liquids and Gases. By Oskar Schrenk. Translation from *Die Naturwissenschaften*, Vol. 17, No. 34, August 23, 1929.
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557. Measurement of Profile Drag on an Airplane in Flight by the Momentum Method. By Martin Schrenk. Part I. Translation from *Luftfahrtforschung*, May 18, 1928.
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559. Ratier Metal Propeller with Pitch Variable in Flight. By Pierre Leglise. From *L'Aeronautique*, December, 1929.
560. The 1929 Rhon Soaring-Flight Contest. By Alexander Lippisch. From *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, February 28, 1930.
561. Improving the Performance of Multi-Engined Airplanes by Means of Idling Propellers—The "Free-Wheel" Propeller. By M. Pillard. From a pamphlet published by Ferran & Co. in 1929, Marseille, France.
562. Experimental Investigation of Aircraft Propellers Exposed to Oblique Air Currents. By O. Flachsbart and G. Krober. From *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, December 14, 1929.
563. Balanced and Servo Control Surfaces. From the *Aeroplane*, February 26, 1930.
564. Recent Tests of Tailless Airplanes. By Alexander Lippisch. From *L'Aerophile*, February 1-15, 1930.
565. Development of the Junkers-Diesel Aircraft Engine. By Dr. Gasterstädt. From *Automobil-technische Zeitschrift*, January 10 and 20, 1930.
566. Experimental Research on the Friction of Pivots. By A. Jaquerod, L. Defossez, and H. Mügeli. From *Journal Suisse d'Horlogerie et de Bijouterie* Nos. 11 and 12, 1922; and Nos. 1, 2, and 3, 1923.
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568. Contribution to the Theory of Propeller Vibrations. By F. Liebers. From *Zeitschrift für Technische Physik*, Vol. X, 1929.



569. A Possible Method for Preventing the Autorotation of Airplane Wings. By Oskar Schrenk. From *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, November 14, 1929.
570. "Gloster" Metal Construction. From *Flight*, April 18, 1930.
571. Propulsion by Reaction. By Maurice Roy. From *La Technique Aeronautique*, January 15, 1930.
572. Impact Tests on Rubber Compression Springs for Airplane Landing Gears. By K. Hohenemser. From *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, March 28, 1930.
573. Air Forces and Air-Force Moments at Large Angles of Attack and How They are Affected by the Shape of the Wing. By Richard Fuchs and Wilhelm Schmidt. From *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, January 14, 1930.
574. Calculation of Pressure Distribution on Airship Hulls. By Theodor von Karman. From Report No. 6 of the Aerodynamical Institute of the Technical High School, Aachen, 1927.
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576. The Vortex Theory and Its Significance in Aviation. By A. Betz. From *Unterrichtsblätter für Mathematik und Naturwissenschaften*, Vol. 34, No. 12, 1928.
577. Determination of the Best Cross Section for a Box Beam Subjected to Bending Stresses. By A. von Baranoff. From 1927 Yearbook of the D. V. L. (Deutsche Versuchsanstalt für Luftfahrt).
578. Calculation of Tapered Monoplane Wings. By E. Amstutz. From *Schweizerische Bauzeitung*, April 5, 1930.
579. Structural Details of German Light Airplanes. By Martin Schrenk. From *Zeitschrift des Vereines deutscher Ingenieure*, March 15, 1930.
580. Theory of the Landing Impact of Seaplanes. By Wilhelm Pabst. From *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, May 14, 1930.
581. Load Assumptions for Calculating the Strength of Airplanes. From D. V. L. Building Specifications for Airplanes.
582. Effects of the End Fixation of Airplane Struts. By Alfred Teichmann. From *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, May 28, 1930.
583. Determination of the Maximum Control Forces and Attainable Quickness in the Operation of Airplane Controls. By Heinrich Hertel. From *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, January 28, 1930.
584. Flight Tests for the Determination of Static Longitudinal Stability. By Hermann Blenk. From the 1930 Yearbook of the D. V. L.

#### LIST OF AIRCRAFT CIRCULARS ISSUED DURING THE PAST YEAR

- | No.  |  |
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| 103. | The Bristol <i>Bulldog</i> (British)—A Single-Seat All-Steel Fighter. From a circular issued by The Bristol Aeroplane Co. (Ltd.), England; and <i>Flight</i> , July 11, 1929.                              |
| 104. | The A. B. Flygindustri <i>K 37</i> (Swedish Junkers)—A Low-Wing All-Metal Military Airplane. Translation from a circular issued by A. B. Flygindustri, Malmo, Sweden.                                      |
| 105. | The Saunders <i>Cuddy Sark</i> Commercial Seaplane (British)—A High-Wing Monoplane Flying Boat. From a circular issued by S. E. Saunders (Ltd.), England.  |
| 106. | The "Morane Saulnier 222" Airplane (French)—A Single-Seat Pursuit Monoplane. By Andre Frachet. Translation from <i>Les Ailes</i> , June 6, 1929.   |
| 107. | The Weymann-Lepere <i>W. E. L. 10</i> Observation Airplane (French)—A High-Wing Monoplane. Translation from <i>L'Aeronautique</i> , November, 1929.  |
| 108. | The Comper C(LA)7 <i>Swift</i> Airplane (English)—A High-Wing Single-Seat Monoplane. From <i>Flight</i> , January 17, 1930.  |
| 109. | The Dornier <i>Do. X</i> Flying Boat (German)—A Giant High-Wing Monoplane. By Claude Dornier. Translation from a lecture before the Wissenschaftliche Gesellschaft für Luftfahrt in November, 1929.        |
| 110. | The Liore-Olivier <i>Le 0240</i> Commercial Seaplane (French)—A High-Wing Cantilever Monoplane. Translation from <i>L'Aeronautique</i> , December, 1929.   |
| 111. | Les Mureaux <i>130A2</i> Observation Airplane (French)—A High-Wing Two-Seat Monoplane. By Andre Frachet. Translation from <i>Les Ailes</i> , November 21, 1929.  |
| 112. | The <i>Latecoere 28</i> Commercial Airplane (French)—A Ten-Passenger High-Wing Monoplane. Translation from a pamphlet issued by the Societe Industrielle d'Aviation Latecoere.                             |
| 113. | The Dyle and Bacalan <i>DB 70</i> Commercial Airplane (French)—An All-Metal High-Wing Monoplane. Translation from a circular of the Societe Aerienne Bordelaise; and <i>Les Ailes</i> , November 14, 1929. |

114. The *Potez 39* Observation Airplane (French)—An All-Metal High-Wing Two-Seat Monoplane. From *L'Aeronautique*, February, 1930.
115. The Farman *F. 300* Commercial Airplane (French)—A High-Wing Semicantilever Monoplane. From a description received from Paris Office, N. A. C. A. See also *L'Aeronautique*, February, 1930.
116. The Junkers *G 38* Commercial Airplane (German)—A Giant High-Wing Monoplane. From *Zeitschrift des Vereines deutscher Ingenieure*, January 4, 1930.
117. The De Havilland *Moth Three* Airplane (British)—A High-Wing Commercial Monoplane. From *Flight*, April 25, 1930.
118. The Junkers *Junior* Light Airplane (German)—A Two-Seat All-Metal Low-Wing Cantilever Monoplane. From a pamphlet published by the Junkers Aircraft Co., Dessau, Germany.
119. The Avro *Trainer* Airplane (British)—A Training Biplane. From *Flight*, May 2, 1930.
120. The Cierva *Autogiro* Mark III (British)—Armstrong-Siddeley "Genet Major" Engine. From *Flight*, May 9, 1930.
121. The Caproni *90 P. B.* Military Airplane (Italian)—A Giant Biplane of 6,000 Horsepower. From *Aeronautica*, April, 1930, and *Bollettino Aeronautica*, Nos. 1-3, January to March, 1930, published by the Caproni Co., Milan, Italy.
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and from a document furnished by the Societe Aerienne Bordelaise.

124. The Wibault *220 R. N. 3* Airplane (French)—A Three-Place Observation High-Wing Monoplane. From *L'Aeronautique*, July, 1930.
125. The Short *Valetta* Commercial Seaplane (British)—An All-Metal High-Wing Twin-Float Monoplane. From *Flight*, July 25, 1930.
126. The Henderson *Hendy 302* Cabin Airplane (British)—A Two-Seat Low-Wing Cantilever Monoplane. From *Flight*, August 22, 1930.
127. The Breguet *270* General-Purpose Military Airplane (French)—A Two-Seat All-Steel Sesquiplane. By R. J. DeMarolles. From *Aircraft Engineering*, September, 1930.

#### BIBLIOGRAPHY OF AERONAUTICS

During the past year the committee issued a bibliography of aeronautics for the year 1928. It had previously issued bibliographies for the years 1909 to 1916, 1917 to 1919, 1920 to 1921, 1922, 1923, 1924, 1925, 1926, and 1927. A bibliography for the year 1929 is now in the hands of the printer and should be ready for distribution during the coming year. A bibliography is now being published annually by the committee. All issues of the Bibliography of Aeronautics to date were prepared by Paul Brockett.

Citations of the publications of all nations are included in the language in which the publications originally appeared. The arrangement is in dictionary form, with author and subject entry, and one alphabetical arrangement. Detail in the matter of subject reference has been omitted on account of cost of presentation, but an attempt has been made to give sufficient cross reference to make possible the finding of items in special lines of research.

## PART V

### SUMMARY OF PROGRESS IN AIRCRAFT DEVELOPMENT

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#### AERODYNAMICS

Previous summaries of the progress in aerodynamic development have called attention to the fact that the main theoretical foundations of this new science have been firmly laid and that the present work is necessarily restricted to extensions of or additions to existing theory. This does not mean that no important theoretical work is being done; it means that practically all of the present work is along lines previously laid out and that no new outstanding general problems are in sight. With this explanation it may be stated with confidence that problems of a basic or fundamental nature are now receiving far more attention than at any time in the past, and that these concentrated efforts are world-wide.

It is necessary to the proper understanding of the work of the National Advisory Committee for Aeronautics that full recognition be given to the conditions under which the committee functions. A very large part of the committee's work is undertaken to meet the immediate needs of air commerce and the military and the naval services. Whenever possible, this type of work is conducted in the form of general investigations which include the specific problems in question, but it is inevitable that a large proportion of the available time and effort must be expended on the specific problems.

For several years the major problems investigated or considered have been concerned with the general subjects of safety in flight, improvement of aerodynamic efficiency, and improvements in general design and operation. The problem of the spin is considered the most important now under investigation, and it is felt that definite progress has been made during the past year. The completion of the new 5-foot vertical wind tunnel enables the committee to concentrate its efforts on a systematic testing program in conjunction with the flight tests now under way. Many problems of aerodynamic efficiency and design which can not be adequately investigated in the variable-density tunnel or the propeller research tunnel can readily be handled in the new 30 by 60 foot full-scale wind tunnel now nearing completion. The testing of full-scale airplanes under the accurately controlled conditions in the new tunnel is certain to extend enormously our knowledge of scale and interference effects, and thus lead to marked improvement in general design.

The increasing importance of seaplanes and flying boats has led the committee to design and construct a seaplane towing channel which will have a capacity adequate for accurate tests under conditions corresponding to those of very large seaplanes with very high landing speeds. This channel, having a length of 2,050 feet and a carriage speed of 40 miles per hour, is scheduled for early completion. It represents a very important addition to the committee's equipment.

There follows below a brief summary of the work done during the past year, with an indication of the lines to be investigated in the future.

*Spinning.*—The airplane spin is considered the most important general problem now under investigation, in that a satisfactory method of prevention or even a positive control would result in a marked increase in safety. The problem resolves into two parts, one concerned with the prevention of involuntary spins near the ground and the other concerned with the recovery from a spin at higher altitudes.

Considerable work has been done on the theory of the spin in this country and abroad, and particularly in England, where the importance of the problem has also long been recognized. During the past year definite progress has been made by the committee, first, with a theoretical study to determine the basic factors for investigation; second, with the provision of a vertical wind tunnel and autorotation dynamometer for the study of changes in models; and, third, by the development of a method for accurate instrumental measurement of flight path, velocities, and attitude as a function of time in actual spins.

Wind-tunnel tests have been made to determine the effect of roll and yaw on rolling moments for various wing shapes and arrangements. Tests have also been made on "floating ailerons" on rectangular and tapered wings. The effect of yaw on rolling moments was very much reduced by taper and by the biplane arrangement. Floating ailerons also reduce the autorotation tendencies. These investigations are being continued.

Flight tests have been made on the NY-1 airplane to investigate the effect of wing loading, balance, and mass distribution on spinning characteristics. Within the limits through which these can be varied with the maximum disposable load, it was found that while many of the spin characteristics changed appreciably,

others—and in particular the number of turns required for recovery—did not change. Tests made with greatly reduced tail surfaces also showed no appreciable change in the time required for recovery. The tests are being continued with another type of airplane, the XN2Y-1, which has a less favorable recovery. These tests are being made with loads that can be so released as to insure recovery from any spin. The present program is to take an airplane which recovers easily and find a loading condition that makes recovery difficult, so that the effect of various changes can be studied under critical conditions.

Another part of this program is the measurement of ellipsoids of inertia as a routine procedure on all available airplanes. These data are being classified according to known spinning characteristics. A new swinging gear developed by the committee enables the moments of inertia to be determined quickly and accurately.

*Structural safety.*—The determination of air loads and load distribution under various conditions of flight continues to be one of the major activities of the flight research section. During the past year the data obtained in pull-ups from dives have been exceedingly important. One of the outstanding results is to show that in the average pull-up the maximum acceleration occurs at a rather low lift coefficient and that some revision of the design loads for rear beams will be necessary. This matter is being carefully investigated by special tests on pressure distribution for low-angle conditions.

Pressure-distribution tests have been completed on three types of wing tips fitted to the Douglas M-3 airplane. The preliminary results indicate that the present design requirements for wing tips are too severe and that some reduction in design loads may be safely made, but it is considered inadvisable to take any action until further data are obtained with other types of wing tips.

In response to requests from operators of air transport lines, a special accelerometer has been developed to give a continuous record of accelerations encountered in bumpy air over long flights. The maximum accelerations so far obtained under moderately severe conditions, described as "very bumpy," appear to range between  $-0.2$  g. and  $+2.0$  g., but it is quite probable that more severe accelerations will be found in extended operation.

Landing and drop tests have been completed on a number of types of landing gears under comparable conditions. These tests are to be continued until definite conclusions are justified. The present indications are that the oleo and rubber-cord types are the most efficient. The low-pressure air wheel, although possessing many desirable qualities, is not a satisfactory shock-absorbing device when used alone.

*Reduction of drag.*—The reduction of drag is obviously one of the most promising methods of improving the airplane. It now appears that the possibilities in this field are much greater than were anticipated when the original cowling investigation was started in the propeller research tunnel. The reduction of drag may logically be divided into two general classes, direct and indirect. A direct reduction is obtained by the use of better forms or a reduction of exposed parts. An indirect reduction is obtained by reducing the interference drag between various parts. The committee is actively engaged in the study of both phases of this subject. The major project in the propeller research tunnel at the present time is the study of the location of power units with respect to the wing or wings.

Another research closely connected with the nacelle-wing interference investigation is that on pusher and tandem propellers. This is a logical continuation of the present work. Models for the preliminary tests are being built and will be available for testing as soon as the necessary electrical equipment can be secured.

Glide tests on a Fairchild cabin monoplane are being supplemented by tests on a model in the variable-density tunnel to determine the component of total drag due to various items. A summary of these items gives the designer a very definite basis on which to effect an improvement. One result of this work has been to point out the great field for improvement in drag of the landing gear. A comprehensive research on landing-gear drag and its possible reduction is to be carried out in the propeller research tunnel.

One phase of this subject is being covered by some very important preliminary tests in the variable-density tunnel on interference between wings, body, and strut intersections. The immediate problem is to discover the particular combinations which produce large adverse conditions and to find the most effective methods of eliminating the adverse effects. The general problem is to discover the general principles underlying the phenomenon so that it will be possible for the designer to predict the interference and to make use of favorable effects. An effort is being made to obtain information of a practical nature in the preliminary investigations to a fundamental research.

*Stability and control.*—In connection with the spinning investigation a series of tests is being made on various types of floating ailerons, which have been revived by the success of the Curtiss Tanager in the recent Guggenheim competition. There is an indication of improvement in lateral control near stalling speeds sufficient to justify this study.

During the past year a study has been made of the factors affecting stability and the measurements required in flight investigations. A program has been prepared for stability tests on a small commercial airplane. The necessary apparatus has been assembled

and is now being installed. A similar program has been prepared on an airplane fitted with slots and flaps. In this case the measurements will include the effect of the slots and flaps, alone and in combination, the vertical velocity at landing, the landing speed, the effectiveness of the controls at low speed, and the effectiveness of the long-travel landing gear in absorbing landing shocks.

*Maneuverability.*—The previous work on flight-path determination has been extended considerably during the past year, with tests on a number of new airplanes. Included in this series were three types of Navy fighters which were flown by a number of Navy pilots in a routine manner, thus giving for the first time a fairly exact knowledge of the flight paths and loads actually encountered in service maneuvers. In this connection it is very interesting to note that the pilots' impressions of relative air loads and flight paths were not in accordance with the actual facts. The airplane which they considered to have the slowest pull-up and the lightest loading actually had the fastest pull-up and the heaviest air loads. This confirms the conclusions from previous work that maneuverability is an inherent quality of an airplane which is brought out by the flight paths obtained under various conditions and that the pilot has very little influence on the final result.

*Airfoils.*—There are being investigated in the variable-density wind tunnel a number of problems concerned with airfoil characteristics. The most important of these is the effect of thickness and mean camber line shape. For this purpose a series of 96 airfoils with systematic variation in thickness, mean camber, and position of maximum thickness has been selected and the tests started.

In extension of previous work full-scale characteristics have been obtained on a number of additional widely used sections. Other investigations recently completed or now on hand include a study of very thick airfoil sections, a study of taper in plan form and section, and a study of the effect of sag in wing surface covering.

Comparative tests recently completed in the variable-density and propeller research wind tunnels show excellent agreement with each other and with flight tests.

*Ice formation.*—The investigation of ice formation and its prevention by the use of chemicals has been continued. It appears probable that no chemical or simple surface treatment will give positive and lasting protection. Tests show, however, that the expanding rubber leading edge developed by Doctor Geer can be made to operate quite satisfactorily and a commercial firm is preparing to place it on the market. An investigation is now being made on the effectiveness and

practicability of internal heating of the wing under various conditions.

*Boundary layer and boundary layer control.*—This subject is now receiving widespread attention in this country and abroad, since there is a possibility that some practical application of great importance may be developed. At the request of the National Advisory Committee for Aeronautics, the Bureau of Standards has extended its previously reported studies on streamline bodies to the study of the boundary layers on flat plates. A number of very important practical results have already come from this work, among which are a better understanding of the effects of turbulence and a rather complete explanation of widely divergent results in various wind tunnels.

During the past year a final report has been prepared on the boundary layer control investigation made at Langley Field to cover the effects of slot position and width with suction and with pressure.

*Propellers.*—The investigation of propeller characteristics as affected by nacelle and wing interference is the major problem now under consideration in the propeller research tunnel. During the past year, as a part of this investigation, measurements have been taken on the effect of locked and idling propellers and also on the effects of pitch and yaw. Reports covering these subjects have been prepared for publication.

Other work completed during the past year includes a direct comparison between two families of propellers differing only in the blade sections, one having the Clark Y type and the other a modified R. A. F. 6 type section. The Clark Y type showed slightly higher maximum efficiencies, but the R. A. F. 6 type showed better efficiencies for climb and take-off conditions.

Tests have also been completed and a report prepared on the effect of cutting off the tips of a metal propeller to obtain smaller diameters. It was found that a reasonable reduction in diameter did not cause any appreciable loss in efficiency.

In addition to the wing and nacelle interference investigation, which will require considerable time for completion, tests are to be run in the future on pusher and tandem propellers.

*Airships.*—The previous work on deceleration tests has been continued with the *TC-6* and the metal-clad *ZMC-2* airships.

Tests have been made in the variable-density tunnel on two wooden models supplied by the Goodyear-Zeppelin Co., the *ZRS-4* and a shorter model of 4.8 fineness ratio. The effect of surface with a high polish, with a normal finish, and with the surface roughened by emery was determined. At higher Reynolds Numbers a coating of emery increased the drag 60 per cent. An appreciable discrepancy was introduced in the results by the changes which took place in the surface of

the wooden models during the tests. This effect was so great that the Goodyear-Zeppelin Co. has supplied a metal model which is now being tested. These tests are to be supplemented by tests in the propeller-research tunnel on a very large wooden model now being constructed at the Washington Navy Yard. The proposed tests on the large model include pressure distributions and control hinge moments, in addition to the usual force and moment readings.

### AIRPLANE STRUCTURES

**TREND OF DESIGN—Standardization of types.**—An analysis of the 128 approved-type certificates issued for new designs by the Department of Commerce during the past year discloses the following interesting trends in design:

That there is a pronounced trend toward standardization, especially in the 2, 3, and 4 passenger airplanes, which amount to 70 per cent of the designs approved.

That monoplanes are more popular with designers than biplanes, the count being 77 to 51.

That biplanes predominate for military types and for 2 and 3 passenger types. There were a number of new and promising monoplane designs which may swing the trend for military types to the monoplane.

That monoplanes appear more popular in the 4 to 6 passenger class.

That there is little to choose between the popularity of open and closed types, there being 63 open and 65 closed types approved.

That closed types predominate in airplanes providing for more than three passengers, indicating a trend to provide for passenger comfort.

That the new designs approved offer an amazing range in passenger capacities of any number from 1 to 13, with other types providing seating capacities for 15, 20, 21, 32, and 33, respectively.

That single-engined types predominate with 114 as compared to five 2-engined types, eight 3-engined types, and one 4-engined type.

That for commercial air transportation the 3-engined monoplane is favored, this type having a power loading which permits taking off with full loads at altitudes up to 7,000 feet and operating at full loads at altitudes up to 10,000 feet.

That for large transports the American designer is handicapped because American engines of 1,000 to 1,500 horsepower are not available, and will not be for a year or two.

That the development of seaplanes, flying boats, and amphibians is lagging as compared with the development of landplanes, the count being 109 landplanes, 7 amphibians, 4 flying boats, 3 seaplanes, and 5 convertible landplanes or seaplanes. Of the 7 amphibians, 5 were biplanes and 2 were monoplanes.

That engine nacelles are located when possible in or below the wing, although the effect of engine location on propulsive efficiency and interference drag, coupled with suppression of vibration and noise, will undoubtedly lead to placing the engines either in the leading edge of or considerably above the wing.

**Amphibian airplanes.**—The number of new designs of amphibians emphasizes the general appreciation of the advantages of this type in the operation of commercial air lines and for military purposes. In latest commercial types the engine is located above the wing, which not only assures freedom from water spray in the operation of the engine and propeller but minimizes the noise transmitted to the passenger cabin. The newer designs are of the twin-engined type.

**Landing gears.**—Landing gears have been practically standardized, and most of the new designs provide for oleo shock-absorbing equipment. Although a number of new type airplanes have appeared with retractable landing gears, this type of gear is not used to any considerable extent, its use being limited to those types of airplanes where very high speed is desirable. An appreciation of the necessity for decreasing the drag of the landing gear is emphasized by the number of new designs where the structure has either been simplified or provision made for the streamlining of the landing gear and the landing wheels.

**Shock absorbers.**—The hydraulic shock absorber is now universally used. This shock absorber is manufactured in a large number of types and sizes, so that it is available even for the smallest design of airplane of the single-passenger type. The air-wheel type of tire having a large cross-sectional area and operating under low air pressures has many desirable qualities but has eliminated the shock-absorbing mechanism, and it has been found that it operates best when used in conjunction with the shock-absorbing gear.

**Wheel tail skids.**—Only a very few of the new designs of small airplanes still provide for the use of a tail skid. In all other types the use of a wheel with either a hard or pneumatic tire has replaced the tail skid. This is especially true in the larger types of airplanes. The almost universal use of the tail wheel is due entirely to the success of wheel brakes on the main landing wheels.

**Brakes.**—Brakes of standard types are available to aircraft manufacturers in combination with the wheel structure. The availability of standard equipment of this character makes possible the use of such equipment on practically every new design.

**Difference between military and commercial types.**—There has been a steady demand for improved performance of military airplanes, particularly for violent maneuvers at high speeds. This demand has made necessary careful consideration of the require-

ments for structural strength, especially on certain bombing types of airplanes, for maneuvers at high speeds.

To provide for sufficient strength in the aircraft structure, it has been necessary to study carefully the load distribution of such types in particular maneuvers, so that the structure can be strengthened only in those parts that are severely stressed. This makes unnecessary the raising of the structural requirements of the whole structure, which would mean an undesirable increase in the weight of the airplane.

Certain types of commercial airplanes, with slight modifications, are suitable for some military uses. This is particularly true of large-type airplanes for the transportation of troops and supplies, and certain designs of the training type.

**STRUCTURAL MATERIALS.**—Although wood still holds a prominent place in aircraft construction, the use of metal, either steel or aluminum alloy, is gradually increasing. Wood and fabric wings will be found on the majority of airplanes, while metal fuselage structures are almost universal practice. However, the large supplies of wood available, together with the information and technical data on the use of wood as a result of research work of the Forest Products Laboratory contained in reports of the committee, indicate that this material will be used to a considerable extent for small airplanes for some time to come.

With the large-type airplanes the tendency is toward the use of metal throughout. The increasing use of metal in the construction of wings and fuselages, particularly aluminum alloy, has made necessary the intensive study of the problem of corrosion. This study has resulted in the development of a number of protective coatings of a very satisfactory type. The problem of producing an aluminum alloy of greater resistance to corrosion is still being investigated.

The study of magnesium alloys has been continued, particularly in connection with their adaptation for use in aircraft construction, and material progress has been made in increasing their physical properties and resistance to corrosion. The use of magnesium has been extended to propeller blades and parts of the engine and aircraft structure. This increased use of this material has made necessary an extended study of coatings for its protection against corrosion. At present an alloy of special manufacture looks more promising from a corrosion-resisting standpoint than magnesium with a protective coating.

There has been an increased use of steel tubing, particularly in airplane structures, with the development of welding technique. The past year has seen a gradual increase in the use of stainless steel, particularly in connection with streamline wires, struts, wing

ribs, and seaplane floats. Fabrication of this material is being studied and one method of spot welding appears to hold considerable promise.

Although the possibilities of beryllium alloys look promising, since they are lighter in weight and have greater strength than aluminum alloys, the cost of production is too great at the present time for serious consideration as a structural material. The indications are that it will not be an important factor, unless a method of producing the material is developed which will substantially lower the cost.

### AIRSHIPS

Airship progress in the United States during the past year, while not striking to the eye, has nevertheless been very real.

In the field of rigid-airship development excellent progress has been made on construction of the *ZRS-4* (U. S. S. *Akron*), the first of the Navy's two new rigid airships. Erection of frames was started November, 1929. The end of 1930 will see complete erection of all the framing except possibly the extreme bow and stern portions and attachment of fin structures. A successful "proof test" for the purpose of checking the calculated strength of the structure has been conducted on a section of the airship near amidships. Engines for this airship have been delivered and tests to date have been satisfactory on the novel transmission to give propeller thrust in four directions—ahead, astern, upward, and downward. It is expected that this airship will be ready for trial flights about the middle of 1931.

Operations of the *Los Angeles* by the Navy and several smaller airships by the Army, Navy, and private interests have continued. The operation by the Goodyear Tire & Rubber Co. of a fleet of several small nonrigid airships for training and advertising purposes has been notably successful.

In order to appraise thoroughly the material condition of the U. S. S. *Los Angeles* after over six years of miscellaneous service, a careful inspection of her was conducted by the Naval Board of Inspection and Survey. This board found the present condition of the *Los Angeles* to be good and saw no reason why she should not be continued in service for two to four years longer.

Important developments in methods for ground handling of rigid airships and in equipment have been under way continuously for the past several years. The past year has seen definite substitution of mechanical handling for man power in several phases of ground handling. Further work is indicated before a final solution satisfactory for all phases of the problem will be reached.



Technical progress along various lines allied to airships has been continued actively. Development in the United States of a solid-injection type engine suitable for airships is under way, but it is too early to predict the outcome of these efforts. The search for more suitable gas-cell material has produced a gelatin-latex fabric that has given very satisfactory results in actual service for a period of nine months. Aerodynamic tests on models of the new naval airships are in progress. An airship envelope is being obtained by the Navy Department with which to conduct full-scale tests with fuel gas as an airship fuel. One phase of this problem is how to handle the repurification of helium that has become polluted with a fuel gas of high hydrogen content. Better cements have been developed for making seams in rubberized fabric. Specifications for fabrics used in lighter-than-air work are in process of revision and standardization. A really satisfactory type of water-recovery apparatus that will not add too much to the resistance of the airship is still greatly needed for helium-filled rigid airships.

With the opening of a new Government plant near Amarillo, Tex., increased quantities of helium have become available at lower unit cost.

Outside the United States, the *Graf Zeppelin* has operated on more or less regularly scheduled flights and generally has carried full passenger lists. Her triangular flight from Europe to South America to the United States in June, 1930, was a striking achievement, second only to her record-breaking voyage around the world in 1929. A new and larger shed has been completed at the Friedrichshafen works of the Zeppelin Co., and work has started on a new and larger airship known as the *LZ-128*.

The two British airships *R-100* and *R-101* had their trial flights late in 1929.

The *R-100* made a round-trip voyage from England to Canada in July and August, 1930. This marked the twelfth crossing of the Atlantic by airships without loss—six westward and six eastward voyages. The Pacific has been crossed once eastward. For nearly two weeks the *R-100* remained based on a mast near Montreal, which is the latest development in a modern mooring mast. Damage to fabric fin covering sustained en route to Montreal was successfully repaired while the airship rode at the mast.

The unfortunate disaster to the *R-101* was a great shock and adds to the toll of those who have sacrificed their lives to the development of airships. In the reports on this disaster which have appeared in the press there is no authentic report which throws suspicion on the structural integrity of the airship. Undoubtedly the large loss of life was a secondary phase of the accident and resulted from hydrogen fire.

## AIRCRAFT ENGINES

An important factor which has influenced aircraft-engine development during the past year has been the lack of production and the consequent activity in connection with the improvement of present types of engines and the development of new types. In one year the number of engines having approved-type certificates has increased from 32 to 64. The largest increase has been in the field of the so-called commercial engines, although improvement has been made in types of engines which were originally designed for military use.

In the field of commercial engines designers have concentrated on the radial air-cooled engine of 100 to 250 horsepower. For lower horsepower there has been a distinct trend toward the inverted in-line type air-cooled engine of either four or six cylinders. The advantage of the inverted in-line type air-cooled engine is fully appreciated by aircraft designers, and for the smaller types of airplanes this type of engine will be favored.

For the military services and for large multi-engined commercial airplanes the radial air-cooled engine of 250 to 575 horsepower is almost exclusively used. For higher horsepower the liquid-cooled engine has so far proved more successful.

No essentially new design has been developed and no startling improvement has been made in aircraft engines. Improvement has been concerned largely with increasing the power output and reliability of existing engine types.

In the radial air-cooled engine the horsepower has been increased by the use of a new design of cylinder which gives a more even distribution of temperature in the cylinder head. Improvement has been made in cooling the cylinder wall by the use of deflectors, which guide the cooling air to the rear of the cylinders.

With the improvement in engine performance, there has been a corresponding increase in aircraft performance, largely due to the general application of cowlings to the radial air-cooled engine installation. Low-drag cowlings of the ring and N. A. C. A. type have been applied, and the effectiveness of the cowling in reducing the resistance of the air-cooled engine is attested by the fact that all the high-speed records in this country in the past year were made with airplanes powered with radial air-cooled engines using the N. A. C. A. type cowling.

With the engineering materials and fuels now available, the maximum power output of radial engines seems to be limited to about 600 horsepower. There is a real demand, both in the military services and in the commercial field, for higher-powered engines. This demand will no doubt be met during the coming year



by the development of liquid-cooled engines of 1,000 to 1,500 horsepower.

The success of the matériel division of the Army Air Corps in the application of liquid cooling and the use of ethylene glycol for engines in the military service has led to the consideration of this type of cooling especially for higher-powered engines.

With the developments in engine design during the past year there seems to be a rather sharp line of demarcation in the application of the air-cooled and the water-cooled engine as measured by the horsepower required. As a result of research, more exact knowledge is now available to the aircraft-engine designer, which makes possible a cylinder design using higher compression ratios and supercharging. In many of the service types of engines experimental results indicate the possibility, with improved design and special fuels, of operating with a compression ratio as high as 7 to 1, and the use of moderate supercharging. The results of laboratory tests indicate the possibility in air-cooled designs of developing 1 horsepower for every 2 cubic inches of piston displacement. The rated horsepower of engines now available of either the commercial or military type is 1 horsepower for every 2½ to 3 cubic inches of piston displacement.

This marked improvement in airplane-engine performance will be the result of a design permitting the use of higher compression ratios with moderate supercharging and special aviation-engine fuels.

Progress has been continued by a number of manufacturers in the development of the compression-ignition engine. The Packard Motor Car Co. has announced and started production of a 9-cylinder radial air-cooled compression-ignition engine. This engine has received an approved-type certificate from the Department of Commerce with a rating of 225 horsepower at 1,950 r. p. m. Development of special engines of this type is being continued by the Allison Engineering Co. and by the Westinghouse Co. for the Bureau of Aeronautics of the Navy Department.

The chief problems facing the designer of compression-ignition engines are to provide a construction with sufficiently light weight and to obtain a higher brake mean effective pressure. The final development of the fuel-injection engine may be a compromise design providing for the use of a fuel-injection system, a low-volatile fuel, and spark ignition.

Special injection systems for the injection of gasoline and other fuels are being developed by the Pratt & Whitney Co. and by the Curtiss-Wright Corporation, the latter for the matériel division of the Army Air Corps. Satisfactory flight performance has been obtained with the Wasp engine fitted with an injection system using either gasoline or light oil.

There has been an increased interest in supercharging, as evidenced by the large number of engines

equipped with superchargers. Investigations conducted at the committee's laboratories show that at sea-level conditions moderate supercharging will greatly increase the brake mean effective pressure without a large increase in maximum cylinder pressure and with a slight decrease in specific fuel consumption.

The engine development for the coming year may tend toward an increase in horsepower in engines of the standard types now available, by refinement in design, increase in compression ratio, increase in operating speeds, and the use of supercharging; the development of higher-powered engines of the liquid-cooled type; and the further development of the small inverted in-line air-cooled engine for use in small commercial airplanes.

Another outstanding factor in aircraft-engine development is the remarkable endurance records which have recently been made, indicating the increase in reliability of American aircraft engines. This increase is undoubtedly due to refinement in design and to the selection of improved materials.

#### SUMMARY

Aviation has made steady and healthy progress during the year 1930. The industry, handicapped by loss of business, extended its efforts to improve its product to meet more exacting demands of the individual purchaser and of the passenger public. This is evident from the increased demand upon the part of the industry for technical information from the committee. Airplanes are now purchased on the basis of proved performance, not only as to safety but also as to economy in operation. The exacting demands of the private operator and owner have required the best efforts of the aeronautical engineer and of the aircraft designer and the use of the latest information resulting from scientific research.

Among the important factors that have contributed to the progress of aeronautics during the past year may be mentioned: Consistent advance in technical development; greatly extended use of aircraft for passenger transportation; the activities of the Aeronautics Branch of the Department of Commerce in providing improved and enlarged facilities in aid of air navigation, including radio beacons, lighted airways, and intermediate landing fields; the activities of the Weather Bureau in providing weather-report services along airways; retrenchment and consolidations within the aircraft industry and elimination of surplus organizations, resulting in a sounder financial structure for the industry as a whole; enactment by Congress of the Watres bill to promote air mail and passenger carrying; well-organized and equipped laboratories for scientific research; schools for training technical personnel and Federal rating of schools for training

student pilots; and last but not least, the great stabilizing factor, the Army and Navy 5-year aircraft procurement programs.

The future of the industry, both manufacturing and operating, is dependent upon the solution of many problems affecting the cost and the operating efficiency of airplanes. These problems are both aerodynamic and structural, involving elimination of unnecessary drag and exact knowledge of air forces to permit of the lightest and most efficient design. Paralleling aerodynamic development there must also be a study of thermodynamic problems, with a view not only to increasing the efficiency and reliability of the present aircraft engine but also to providing an engine of a lower power-weight ratio and of increased reliability. Operation difficulties require further study of problems affecting the safe navigation of aircraft in fog, or under conditions where navigation must be entirely by instruments or by the aid of the radio beacon.

The aerodynamic problems demanding solution are those affecting the safety of the airplane, and especially satisfactory control at stalling and landing speeds; the reduction of the landing speed of the airplane; and the decrease of parasite resistance. To achieve minimum air resistance in flight there must be comprehensive investigations of the design of the landing gear, of the proper location of the engines, of the design of the wing, and of its geometrical arrangement with the fuselage.

Under this heading also come the problems involving freedom from noise and vibration in aircraft. As the comfort of passengers must be increased, the difficult problems of eliminating propeller noise, engine exhaust noise, and vibration, become of pressing importance and are receiving all possible attention.

The aircraft power plant is the heart of the airplane. The safety element is largely dependent upon its reliability. The economy of fuel consumption of the engine is an important factor in the cost of operation. Through improved design and the careful selection of proper materials, the reliability of aircraft engines has been greatly increased, as has been proved by the number of endurance records which have been established during the past year.

Much attention is being given the problem of retaining or improving the reliability of the present engine and at the same time, by means of supercharging and the use of special fuel, increasing its horsepower for a given weight 20 or 30 per cent, with a reduction in fuel consumption per horsepower-hour. To eliminate or reduce crash fires much attention is being given the development of the compression-ignition engine.

Future growth will require that additional airways be established and equipped; that weather report service along airways be increased; that passenger travel

be made more comfortable and reliable; and that uniform State legislation be enacted that will harmonize with existing Federal laws and regulations.

In the last analysis, however, the future of aviation may be said to depend upon the degree to which safety is increased and costs are reduced. The answer to these fundamental problems is to be found through the continuous prosecution of organized scientific research.

The recent remarkable performances of the German airship, the *Graf Zeppelin*, including especially its flight around the world and its triangular flight between Europe, South America, and North America, have demonstrated that it is practicable to build and operate large rigid airships successfully. The shocking disaster to the British *R-101* is now being thoroughly investigated and we may know ultimately whether the design, construction, or operation of that airship was to blame. Irrespective of the cause of the crash, it is obvious that the loss of life was primarily and probably altogether due to the use of hydrogen. Our natural resources of helium give to the United States a great advantage in airship operation.

Airships are considered to have great potential value for both commercial and military purposes. The committee believes that their values should be developed thoroughly until they are fully demonstrated; that there should be an airship industry; and that airship lines should be established on a basis that will give to the United States an airship merchant marine. In the opinion of the committee the best policy that can be followed at the present time with respect to airships is to give firm support to the present Navy rigid airship development program.

The committee believes that the 5-year aircraft-construction programs of the Army and Navy have not only been fully justified from considerations of national defense, but also have had a most salutary effect on the efficiency and morale of the Army and Navy air organizations and have exerted a stabilizing influence on the aircraft industry. Wherefore the committee recommends adherence to the principle of aircraft-construction programs continuing over a period of years.

The committee believes that the establishment of air-navigation facilities and the furnishing of weather-report service are vital to the future of air transportation in the United States, and that these activities should be extended and improved as rapidly as practicable.

The committee believes that a serious handicap to the use of air transportation, particularly over short distances, is the remote location of airports from centers of cities and the consequent loss of time on the part of air travelers.

## CONCLUSION

Closer attention to fundamentals has brought about material improvement in the performance, reliability, and safety of aircraft. There has developed among manufacturers a keener competition to produce better aircraft, and this has greatly accelerated the engineering application of the fruits of scientific research.

The research programs of the committee are carefully prepared in the light of the facilities and funds available, and with information and advice as to the needs of aviation furnished by the air organizations of the War, Navy, and Commerce Departments. These programs cover broadly the whole field of aeronautics and are framed to serve commercial as well as military needs, utilizing to the best advantage the

facilities of the committee's aeronautical laboratory and the existing facilities of other agencies. The committee believes that the most effective answer to the outstanding general problems of increasing safety and of reducing costs is to be found through the continuous prosecution of well-organized scientific research, and accordingly the committee recommends continued support of its work in the fields of pure and applied research on the fundamental problems of flight.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE

FOR AERONAUTICS,

JOSEPH S. AMES, *Chairman*.